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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-7

LOW-GROUND-PRESSURE CONSTRUCTION EQUIPMENT FOR USE IN DREDGED MATERIAL CONTAINMENT AREA OPERATION AND MAINTENANCE: PERFORMANCE PREDICTIONS

by

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August 1977

Final Report

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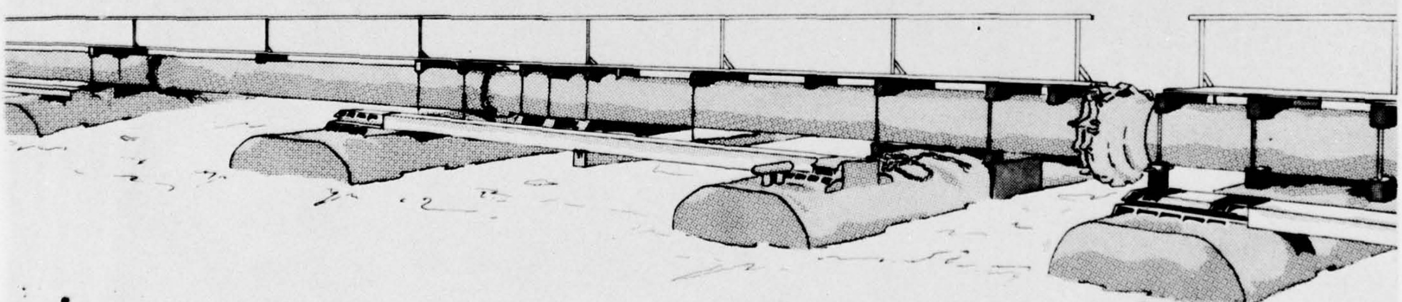

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TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of the research efforts (work units) initiated to date as part of Task 2C (Containment Area Operations) of the Corps of Engineers Dredged Material Research Program (DMRP). Task 2C is included as part of the Disposal Operations Project (DOP) of the DMRP, which among other considerations includes research into various ways of improving the efficiency and acceptability of facilities for confining dredged material on land.

2. Confining dredged material on land is a relatively recent disposal alternative to which practically no specific design or construction improvement investigations, much less applied research, have been addressed. Being a form of waste product disposal, dredged material placement on land has seldom been evaluated on other than purely economic grounds with an emphasis nearly always on lowest possible cost. There has been a dramatic increase in the last several years in the amount of land disposal necessitated by confining dredged material; hence increased attention is being directed toward improving the design, construction, and management of these containment areas.

3. DMRP work units have investigated improved facility design, construction, and management for increasing storage capacities with both economic and environmental protection benefits. Work in and around containment areas often requires special equipment because of the soft dredged material and foundation conditions usually associated with such areas. Consequently the total picture would be incomplete without an assessment of vehicles or equipment that can perform productive work in containment areas. To this end, the investigation reported herein was accomplished by the U. S. Army Engineer Waterways Experiment Station's Mobility and Environmental Systems Laboratory. This is the second of three studies that will provide guidance for the selection of equipment for use in and around containment areas.

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4. The operational environments at 45 sites in nine Corps of Engineers Districts throughout the United States were characterized based on soils data. Performance predictions were made for various low-ground-pressure vehicles based on generalized soil-vehicle relations developed at WES through many years of research in soil-vehicle interactions. Data collected indicated that soft soils are much more prevalent than firm soils, with most sites exhibiting soil strengths requiring vehicles with relatively low ground pressures for extended operations.

5. Three basic work functions were identified as necessary to adequately operate and maintain a confined disposal area: survey and reconnaissance, trenching, and earthmoving. Survey and reconnaissance vehicles are presently available only to a limited extent. Many smaller lightweight vehicles are capable of making single passes in an area but are unable to perform work requiring multiple passes. Conventional trenching machines and earthmoving equipment require firm soils on which to operate and consequently were predicted to negotiate only about 50 percent of the areas sampled. Unique or specialized types of equipment designed specifically for soft-soil operations were predicted to negotiate more than 95 percent of the areas sampled and could perform functions other than survey and reconnaissance.

6. Initial tests with the Riverine Utility Craft (RUC) in Mobile, Alabama, indicate that this vehicle bridges the transitional zone between the fluid and semisolid states. The RUC was found to be capable of performing many useful functions relative to dewatering and consolidating dredged material. Two towed ditching and trenching implements fabricated for use with the RUC in soft-soil operations were also evaluated.

7. The third phase of the vehicle performance study (now complete), which synthesized performance information on various pieces of field-tested equipment, provides detailed guidance for the selection of equipment to be used in and around confined dredged material disposal areas. The synthesis report, "Assessment of Low-Ground-Pressure Equipment Containment Operation and Maintenance," is being published both as Technical Report D-77-8 and an Engineer Manual.

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~~Appendix A, "Data Summary and Site Description for Sampled Containment Areas" was produced on microfiche and is enclosed in an envelope inside the back cover of this report.~~

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Consolidation	Off-road mobility	Soft soils
Construction equipment	Off-road vehicles	Soil-vehicle interaction
Containment areas	Performance predictions	Trafficability prediction
Dewatering	Riverine utility craft	Vehicle performance
Dredged material disposal		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Sufficient soils data were collected to characterize the operational environments in dredged material containment areas in nine Corps of Engineer districts in the United States so that performance of low-ground-pressure vehicles operating in these areas could be predicted. These performance predictions are made using the collected soils data and generalized soil-vehicle relations developed at WES through many years of research in soil-vehicle interactions. In addition, the initial dewatering efforts in dredged material containment areas at Mobile using the Riverine next page

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cont Utility Craft (RUC) are appraised as an indication of the direction future efforts should follow in dewatering and consolidating dredged material containment facilities.

Data collected at 45 sites indicate that soft soils are much more prevalent than firm soils, with nearly 80 percent of the sites exhibiting critical layer soil strengths less than 50 RCI, criteria which require vehicles with relatively low ground pressures for extended operations. Three basic work functions appear necessary in dredged material containment area operations: survey and reconnaissance, trenching, and earthmoving. At present, only survey and reconnaissance vehicles are commercially available to any limited extent. Based on the vehicle analysis in this study, only unique or specialized equipment, specifically designed for soft-soil operations are predicted to negotiate more than 95 percent of the areas sampled and perform functions other than survey and reconnaissance. Many of the smaller lightweight vehicles are capable of making single passes over these areas, but would not be able to perform any work-related functions requiring multiple passes of the vehicle in the same path. Conventional trenching and earthmoving equipment capable of moving material in the sampled areas to create ditches, move dredged material, or build cross-dikes, require firm soil on which to perform such activities, and consequently are predicted to negotiate only about 50 percent of the areas sampled.

Although not tested in a field environment, two towed ditching and trenching implements fabricated for soft-soil operations should assist vehicles without on-board trenching equipment in dewatering selected dredged material containment areas on a limited basis.

Tests with the Riverine Utility Craft (RUC) in Mobile indicate that the vehicle bridges the transitional zone in dredged material containment area development from the fluid state following disposal to the semi-solid state after desiccation and consolidation. During this development process the RUC is capable of performing many useful functions relative to dewatering and consolidation. Also RUC operations appear to be the initial phase in any progressive dewatering program in which the growth of surface crust is required for future activities in the dredged material containment facility.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

PREFACE

The study reported herein was conducted from May 1975 to May 1976 by personnel of the Mobility Systems Division (MSD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES), for the Dredged Material Research Program (DMRP), Environmental Effects Laboratory (EEL), WES, under DMRP Work Unit 2C09B, "Development of Concepts Using Low-Ground-Pressure Construction Equipment for Containment Area Operation and Maintenance (Development of Field Evaluation Investigations)." An earlier report presented an equipment inventory.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief, MESL, A. A. Rula, Chief, MSD, and E. S. Rush, Chief, Mobility Investigations Branch (MIB). The study was under the direct supervision of Messrs. N. C. Baker, Task Manager, Task 2C, and C. C. Calhoun, Disposal Operations Project Manager, EEL, and the general supervision of Dr. John Harrison, Chief, EEL. Messrs. S. M. Hodge and C. R. May, MIB, directed the field data collection. Mr. W. E. Willoughby, MIB, directed the data analysis and wrote the report.

Acknowledgment is made for the assistance of numerous Corps of Engineers personnel at the District offices visited in this study. WES personnel were well received at each location, provided adequate maps and drawings relative to the representative areas selected for the visit, and in most cases guided to each area and explained details of disposal operations for the area. This detailed information allowed full use of the time allotted for data collection within each District, and the contribution of these personnel to the success of this study is acknowledged.

COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors at WES during the conduct of this study and preparation of this report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
millimetres	0.03937007	inches
metres	3.280839	feet
	U. S. Customary to Metric (SI)	
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square inches	645.16	square millimetres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
acre-feet	1233.482	cubic metres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force)	4.448222	newtons
kips	4448.222	newtons
pounds (force) per square inch	6.894757	kilopascals
miles (U. S. statute) per hour	1.609344	kilometres per hour
horsepower	745.6999	watts
horsepower per ton	83.82	watts per kilonewton
degrees (angular)	0.01745329	radians

LOW-GROUND-PRESSURE CONSTRUCTION EQUIPMENT FOR USE IN DREDGED MATERIAL CONTAINMENT AREA OPERATION AND MAINTENANCE - PERFORMANCE PREDICTIONS

PART I: INTRODUCTION

Background

1. In Fiscal Year 1974 an investigation was conducted to determine the potential of using low-ground-pressure vehicles to improve construction and maintenance methods associated with management of dredged material containment facilities. Specifically, the investigation was designed to inventory available low-ground-pressure vehicles, prepare a catalog of selected vehicles with potential for performing tasks in dredged material containment areas, and assess the anticipated performance of the vehicles in certain areas.[1] The performance assessment was based on a limited field data collection program conducted at a total of five disposal areas located in the U. S. Army Engineer Districts of Mobile, Savannah, and Norfolk.

2. Another study was initiated in Fiscal Year 1975 to characterize the operational environments in disposal areas in several additional Corps of Engineer Districts where containment area operation and maintenance problems were considered representative of those throughout the United States. Data were collected relative to soil, water, vegetation, and location problems within the disposal areas. In addition, personnel responsible for dredging disposal operations within each District were consulted relative to past and future vehicle requirements necessary for management of disposal areas within each District. Problems were also discussed relative to transportation of operational equipment between disposal areas, modification of existing construction equipment to satisfy singular requirements for disposal area operations, and possible development of vehicle selection criteria such that specific relations could be developed to assist District personnel in selecting the proper equipment for various disposal area management operations.

3. Concurrent with visits to the Districts, a field test program was initiated to assess the feasibility of using an experimental test vehicle, the Riverine Utility Craft (RUC), to create surface ditches and perform other management tasks in dredged material containment areas at Mobile, Alabama. Although the RUC was originally designed for military use, its amphibious and propulsive characteristics indicated that the vehicle might be useful in creating ditches to remove surface water in containment facilities to permit dewatering or densification efforts by more conventional methods.

Purpose and Scope

4. The overall purpose of this study was to characterize the operational environments associated with dredged material containment areas so that performance could be predicted for some low-ground-pressure vehicles inventoried previously.[1] The performance predictions were made using generalized equations derived through many years of research in soil-vehicle interactions.

5. The specific purpose was to characterize as many representative sites as possible relative to soil, water, vegetation, and location problems. The data collected were used to catalog soil-water-vegetation combinations and to provide a basis for predicting the performance of selected vehicles from the inventory. Most of the representative sites selected were used annually in disposal operations and the data collected should represent a relatively constant type of environment within the Districts on an annual basis.

6. In conjunction with this phase of study, the related performance of the RUC in dredged material containment areas in Mobile was evaluated based on ditching and surface-mixing operations and execution of specific jobs analagous to operations in containment areas.

7. A field data collection program was conducted to determine the magnitude of the supporting strength provided for ground-crawling equipment operating in areas in the following six CE Districts: Detroit, Chicago, New Orleans, Seattle, Philadelphia, and Galveston.

Each disposal area was divided into data collection sites for sampling. Pertinent soil data were collected using methods described in Reference 2, and data relative to vegetation and water location and depth were measured. Pertinent photographic coverage was included to assist in comparing sites at different locations with regard to vegetation coverage and surface water. The soil characteristics obtained were used with inventoried vehicle data to assess performance capabilities derived from elements of the U. S. Army Materiel Development and Readiness Command (DARCOM) ground mobility model, or AMM (formerly AMC-71), now in computer storage at WES. A description of the AMM, the methodology used to predict vehicle performance, and the operational environment characterized in the Savannah, Norfolk, and Mobile Districts are included in Reference 1. Results for the other six Districts will be reported herein.

8. In addition to vehicle evaluations, towing forces in generalized soil-water-vegetation schemes were predicted for two towed ditching implements in combination with selected vehicles from the inventory. Data for the force predictions were obtained from agricultural literature[3] and WES data extrapolations for soils in which strengths increased with depth.[4] In the containment areas the reverse is usually true; i.e., the crust formed over the viscous material is usually the firmest portion of the soil strength-depth profile. The assumption that in ditching efforts in the containment areas the vehicles would generally be limited to crust operation permitted application of the force data described previously.

9. Partial results of dewatering and densification efforts at Mobile with the RUC are also included herein. Initially, ditching efforts using drainage paths created by the RUC propulsion elements (Archimedes screws) were evaluated, followed by repetitive traffic in the initial vehicle ruts at 4- to 6-week intervals. The later efforts removed new surface water from rainfall in addition to any subsurface water that had been moved by gravity into the ruts deepened by repetitive traffic.

Definitions

10. Certain special terms used in this report are defined below:

a. Coarse-grained soil. A soil of which more than 50 percent of the grains, by weight, will be retained on a No. 200 sieve (0.74 mm*).

b. Cone index (CI). An index of the shearing resistance of a medium obtained with a cone penetrometer. The value obtained represents the vertical resistance of the medium to penetration at 6 ft/min of a 30-deg cone of 0.5-in.^{2} base or projected area. The value, although usually considered dimensionless, actually denotes pounds of force on the handle divided by the area of the cone base in square inches (i.e. pounds per square inch).

c. Critical layer. The layer of soil that is most pertinent to establishing relations between soil strength and vehicle performance. For 50-pass performance in fine-grained soils and sands with fines, poorly drained, it is usually the 6- to 12-in. layer; however, it varies with weight and type of vehicle and with soil strength profile. For one-pass performance, it is usually closer to the surface.

d. Fine-grained soil. A soil of which more than 50 percent of the grains, by weight, will pass a No. 200 sieve (smaller than 0.74 mm in diameter).

e. Mobility index (MI). A dimensionless number used to estimate the vehicle cone index, which results from a consideration of certain vehicle characteristics.

f. Rating cone index (RCI). The product of the remolding index and the average of the measured in situ cone index for the same layer of soil. The index is valid only for fine-grained soils and sands with fines, poorly drained.

g. Remolding index (RI). A ratio that expresses the proportion of original strength of a medium that will be retained after traffic of a moving vehicle. The ratio is determined from CI measurements made before and after remolding a 6-in.-long sample using special apparatus.

h. Sand. A coarse-grained soil with the greater percentage of the coarse portion (larger than 0.74 mm) passing the No. 4 sieve (4.76 mm).

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units, and vice versa, is given on page 4.

i. Sand with fines, poorly drained. A sand that contains some fines and is slow draining when wet. Such sands exhibit behavior similar to wet, fine-grained soils under vehicular traffic.

j. Unified Soil Classification System (USCS).[5] A soil classification system based on identification of soils according to their textural and plasticity qualities and on their grouping with respect to their engineering behavior.

k. Vehicle cone index (VCI). The minimum soil strength in the critical soil layer in terms of RCI for fine-grained soils and CI for coarse-grained soils required for a number of passes of a vehicle, usually 1 or 50 passes. As the values of VCI decrease the go-no go performance capability of a vehicle increases.

l. VCI_1. Experimentally determined minimum CI or RCI of the critical layer required for a vehicle to complete one pass. The one-pass critical layer for most vehicles is usually the 0- to 6-in. layer.

m. VCI_{50}. Experimentally determined minimum RCI of the critical layer required for a vehicle to complete 50 passes in a fine-grained soil. VCI_{50} is computed for a given vehicle by first calculating an MI from selected vehicle characteristics and then converting the MI to VCI_{50} by means of a curve or table.

PART II. COLLECTION OF DATA FROM REPRESENTATIVE DREDGED MATERIAL CONTAINMENT AREAS

11. Pertinent data were collected in dredged material containment areas where initial surveys indicated a high probability of a range in operational environments. The areas were selected as being representative of most dredged material containment facilities used by CE. A total of 45 areas were selected within six CE Districts: 5 in Detroit, 3 in Chicago, 10 in New Orleans, 6 in Seattle, 7 in Philadelphia, and 14 in Galveston. Additionally, data were resampled in two Mobile District areas to determine if any increase in soil strength had occurred since the previous sampling.[1]

Data Collected and Collection Procedures

12. Schematic maps of the sampled areas were prepared that delineated boundaries, where possible, between fine- and coarse-grained soils and indicated sample sites within each area. In most areas, aerial photos and field reconnaissance were used in establishing boundaries and locating sample sites. Locations of surface water or other surface features were shown on the schematics, where applicable, to delineate possible soil type or soil strength changes.

13. Sufficient data were collected in each area to describe the areas for mobility purposes and to provide a data base from which vehicle performance predictions could be made over a range of vehicles, work functions, and operational environments to be expected on a Corps-wide basis. Data were collected relative to soil surface conditions (surface water, vegetative cover, etc.) and soil composition. Areal photographs were taken to show surface conditions at the time of data collection.

14. Ten sets of cone penetrometer readings were taken in each sample site. Each set of readings consisted of cone index measurements at the surface (in the case of free surface water, surface readings were taken at the soil surface), at 1-in. vertical increments to a depth of 6 in., then at 3-in. vertical increments to a depth of 18 in., and

finally at 6-in. vertical increments to a depth of 36 in. Representative bulk samples were taken from the 0- to 12-in. depth at each site for laboratory determination of soil type according to the USCS. Representative soil samples were also collected for laboratory determination of moisture content and soil dry density to a depth of 12 in. The depth to the water-table surface was measured at sites where the subsurface water was allowed to reach a state of equilibrium in the sample holes. Remolding index was measured at representative sites in most areas where soil and water conditions indicated potentially valid samples. (In most soil-vehicle relations for fine-grained soils, the remolding index is multiplied by the cone index to obtain a rating cone index (RCI), which more accurately describes soil strength changes with vehicle traffic.) The soil data from all sites were grouped by soil type to dilute any possible effects of remolding within soil groups and allow comparison within soil types by RCI variations.

Description of Areas

15. The dredged material containment areas visited in this study are described and pictured in Appendix A. Basic cone index data from each area are listed in Table A1 and soils data are summarized in Table A2. Each area is pictured with a sketch in Plates A1-A47, showing data collection sites established. In most areas the soil conditions were so poor that data sites could be selected only along the perimeter of the area with the soil actually too soft or wet out near the center to support the data collectors.

16. In general, most of the data collected in these areas can be summarized into several common conditions relative to operation of ground-crawling equipment. The most commonl ondition (to be discussed more fully in later paragraphs) was very low soil strength. Most of the areas contained some soft soil of low strength and in some instances most of each area was still soft even though disposal operations had been completed almost a year earlier. Some crust of varying thickness, depending on climatic conditions, had formed such that

limited vehicle mobility was possible using very low-ground-pressure vehicles. Also, some surface water of less than 12-in. depth was present generally in low spots or around the drainage structures. Most of the fine-grained soils were located farthest away from the influent pipe with the coarser materials deposited near the pipe discharge point. Very little vegetation was present due to the annual disposal operations, which prevented any sustained growth over a period of years before inundation in subsequent disposal operations. Average area size for the representative areas sampled was 250 to 300 acres, although the area size ranged from 18 to 4000 acres.

17. Although most of the District personnel consulted were uncertain as to present vehicle requirements necessary to operate and manage dredged material containment areas, they were in agreement that vehicles of some type were needed to perform certain operational tasks in the areas. Most of the personnel were unfamiliar with various vehicle operations and presently used no techniques for selecting vehicles to operate in the areas at specific times, nor did they possess methods of monitoring increases in soil strength and surface crust with time. Consequently, the general consensus was that vehicles were required to perform most management functions within the containment facilities and that all Districts should follow some organized method of vehicle selection based on the job to be performed and the areal conditions within the facilities. Also some estimate of anticipated vehicle performance was required in order to monitor vehicles operating under contract and examine their performance and efficiency relative to contractural requirements.

Observations

18. Some pertinent observations relative to comparative conditions in the dredged material containment areas were made in the visits to the six CE Districts described herein. In many of the fine-grained soil areas, drainage conditions were relatively poor, generally a

direct result of dredged material disposal techniques. This points out a conflict in obtaining high quality effluent during disposal operations and good surface drainage after dredging has been completed. The discharge pipe from the dredge usually was placed in corners or along the sides of the areas opposite the internal water removal systems (sluices, weirs, culverts, etc.) to increase the effectiveness of the containment area during dredging operations. The discharge pipe generally remained at the same location during an entire discharge operation. Water from subsequent decantation or rainfall ponded in depressions or along the levees opposite the sluices or culverts and usually remained there until drying conditions (evaporation) exceeded precipitation and decantation, usually during the summer months. Consequently, some of the areas were extremely soft and wet or covered with surface water, even though the areas had not been used for disposal in a year or two. It appeared that use of well-planned surface drainage techniques would have removed the surface water sooner and allowed drainage to continue in the areas throughout the duration of the natural desiccation/consolidation processes, quite possibly increasing drying through natural drying process and increasing crust thickness as a function of detention time.

19. Another areal feature quite evident in these visits was the poor placement of inadequate numbers of internal drainage structures within the perimeter of the dredged material containment areas. The weirs and sluices used to drain decanted water and rainfall in most areas were placed too far away from the outfall pipe to be efficient; and, in most cases, only one or two weirs or sluices were used per area regardless of facility size, which in some cases was 4000 acres. This so restricted the drainage paths that internal water removal was usually very slow and easily stopped by surface crust formation or vegetation growth.

20. In association with drainage problems, there appeared to be some general relaxation in maintenance procedures in the areas. Some of the weirs and sluices were blocked by debris such as logs, stumps, and dead vegetation or by crusted material from wind-created wave

action or flow patterns from drainage. Some weirs were blocked by vegetation or by the stop logs of the weirs themselves. Regular maintenance activities or at least regular observation of the areas to identify problems should prevent or alleviate most of these problems.

21. In all fairness to the CE personnel involved, the lack of survey or reconnaissance vehicles capable of negotiating the relatively inaccessible areas following disposal usually contributed to inadequate maintenance of the areas. The realization that most maintenance or dewatering techniques in these areas necessarily require some form of "soft-soil-performance" vehicle prompted the analysis herein. Validation of the vehicle performance predictions reported herein should lead to the development of procedures for staged dewatering programs designed to increase the desiccation/consolidation processes and reduce dredged material containment facility detention time.

PART III. DATA ANALYSIS

Methodology

22. The methodology used herein to predict vehicle performance was developed through years of field testing with military and conventional vehicles. The methodology consists, in part, of experimental relations for vehicle drawbar pull and motion resistance in terms of measured soil strength parameters. The standard measure of soil strength used in vehicle relations is obtained with the WES cone penetrometer and is expressed as either cone index (CI) for coarse-grained soils or rating cone index (RCI) for fine-grained soils.* Unlike coarse-grained soils, very soft fine-grained soils do not ordinarily increase in strength with vehicle passage, but are remolded by passage and tend to lose some of their original in situ strength.

Computation of VCI

23. To compare different vehicles operating in similar soil conditions, each vehicle whose performance is predicted is assigned a given vehicle cone index (VCI) for a prescribed number of passes, usually 1 (VCI_1) or 50 (VCI_{50}).[1] The VCI_1 or VCI_{50} is obtained by first computing the mobility index (MI) as shown in Figures 1 and 2. The calculated MI is then substituted into one of the following equations to obtain VCI_1 or VCI_{50} for fine-grained soils:

a. For tracked vehicles:

$$VCI_1 = 7.0 + 0.2\ MI - [39.2 \div (MI + 5.6)] \quad (1)$$

$$VCI_{50} = 19.27 + 0.43\ MI - [125.79 \div (MI + 7.08)] \quad (2)$$

b. For wheeled vehicles:

$$VCI_1 = 11.48 + 0.2\ MI - [39.2 \div (MI + 3.74)] \quad (3)$$

$$VCI_{50} = 28.23 + 0.43\ MI - [92.67 \div (MI + 3.67)] \quad (4)$$

---

* See paragraph 10 for definition of terms.

Tracked

Vehicle ______________________________ Weight ______________

Track Description ______________________________________

$$\text{Mobility Index} = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6)\right] \times (7) \times (8)$$

Where

(1) Contact Pressure Factor $= \dfrac{\text{Gross weight, lb}}{\text{Area of tracks in contact with ground, sq in.}}$ = __________ = __________

(2) Weight Factor :
<50,000 lb = 1.0
50,000 to 69,999 lb = 1.2
70,000 to 99,999 lb = 1.4
≥100,000 lb = 1.8
= __________

(3) Track Factor $= \dfrac{\text{Track width, in.}}{100}$ = ____________________ = __________

(4) Grouser Factor :
<1.5 in. high = 1.0
>1.5 in. high = 1.1
= __________

(5) Bogie Factor $= \dfrac{\text{Gross wt} \div 10}{\text{Total no. bogies in contact with ground} \times \text{area of 1 track shoe}}$ = ______ = __________

(6) Clearance Factor $= \dfrac{\text{Clearance, in.}}{10}$ = ____________________ = __________

(7) Engine Factor :
>10 hp/ton = 1.00
<10 hp/ton = 1.05
= __________

(8) Transmission Factor :
Hydraulic = 1.00
Mechanical = 1.05
= __________

$$\text{Mobility Index} = \left[\frac{\quad\times\quad}{\quad\times\quad} + \_\_\_ - \_\_\_\right] \times \_\_\_ \times \_\_\_$$

Mobility Index = __________

Vehicle Cone Index = __________

Figure 1. Form used to determine mobility index for self-propelled tracked vehicles in fine-grained soils

Wheeled

Vehicle ______________________ Weight ______________

Tire Description ______________________________

$$\text{Mobility Index} = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6)\right] \times (7) \times (8)$$

Where

(1) Contact Pressure Factor $= \dfrac{\text{Gross weight, lb}}{\text{Tire width, in.} \times \dfrac{\text{Outside diam of tire, in.}}{2} \times \text{No. of tires}}$ = ______

	WEIGHT RANGE, lb $\left(\dfrac{\text{Gross Vehicle Wt, lb}}{\text{No. Axles}}\right)$	WEIGHT FACTOR EQUATIONS	
(2) Weight Factor :	<2000	$Y = 0.553X$	
	2000 to 13,500	$Y = 0.033X + 1.050$	
	13,501 to 20,000	$Y = 0.142X - 0.420$	= ______
	>20,000	$Y = 0.278X - 3.115$	

$$X = \frac{\text{Gross Vehicle Wt (kips)}}{\text{No. of Axles}} \qquad Y = \text{Weight Factor}$$

(3) Tire Factor $= \dfrac{10 + \text{tire width, in.}}{100}$ = ______________ = ______

(4) Grouser Factor : With chains = 1.05; Without chains = 1.00 = ______

(5) Wheel Load Factor $= \dfrac{\text{Gross weight, kips}}{\text{No. of wheels (Duals as one)}}$ = ______________ = ______

(6) Clearance Factor $= \dfrac{\text{Clearance, in.}}{10}$ = ______________ = ______

(7) Engine Factor : >10 hp/ton = 1.00; <10 hp/ton = 1.05 = ______

(8) Transmission Factor : Hydraulic = 1.00; Mechanical = 1.05 = ______

$$\text{Mobility Index} = \left[\frac{\_\_ \times \_\_}{\_\_ \times \_\_} + \_\_ - \_\_\right] \times \_\_ \times \_\_$$

Mobility Index = ______

Vehicle Cone Index = ______

Figure 2. Form used to determine mobility index for self-propelled wheeled vehicles in fine-grained soils

24. As an example of the use of Figures 1 and 2 and equations 1-4 in paragraph 23, the computation of VCI_1 and VCI_{50} for the vehicle conditions given below is as follows:

a. Vehicle conditions (assumed):

(1) tracked vehicle - gross vehicle weight 30,000 lb

(2) track width and length of track in contact with ground surface - 18 x 80 in. (per track)

(3) track grouser height - 1.55 in.

(4) total number of rollers or bogies supporting track along ground surface - 5 per track

(5) area of one track shoe - 18 x 6 in. or 108 in.^{2}

(6) ground clearance under tractor - 12 in.

(7) gross engine horsepower ÷ gross vehicle weight in tons - 125 ÷ 15 or 8.3

(8) transmission type - mechanical = 1.05

b. Using Figure 1 for tracked vehicles

(1) contact pressure factor = 30,000 lb/2x18x80 = 10.42

(2) weight factor = 1.0

(3) track factor = 18/100 = 0.18

(4) grouser factor = 1.0

(5) bogie factor = 3000/10x108 = 2.78

(6) clearance factor = 12/10 = 1.2

(7) engine factor = 1.05

(8) transmission factor = 1.05

$$\text{Mobility Index (MI)} = \left[\frac{(1) \times (2)}{(3) \times (4)} + (5) - (6)\right] \times (7) \times (8) \quad \text{or}$$

$$MI = \left[\frac{10.42 \times 1.0}{0.18 \times 1.0} + 2.78 - 1.2\right] \times 1.05 \times 1.05 = 65.6$$

c. Using equations (1) and (2), paragraph 23

$$VCI_1 = 7.0 + 0.2\ (65.6) - [39.2 \div (65.6 + 5.6)] = 20$$

$$VCI_{50} = 19.27 + 0.43\ (65.6) - [125.79 \div (65.6 + 7.08)] = 46$$

25. Similar equations exist for coarse-grained soils, but only the performance predictions for fine-grained soils will be discussed at this time since only fine-grained soils are critical with respect to operations in dredged material containment areas. When RCI equals VCI , it is assumed that a vehicle can develop no drawbar pull and that all effort generated by the vehicle is required to overcome the motion resistance created by the soil-vehicle interaction. If a vehicle must do work in addition to just propelling itself (VCI_1), the necessary thrust requires additional soil strength. Thus, RCI minus VCI_1 , or RCI_x , is a measure of the additional or excess soil strength that will allow the vehicle to develop additional thrust. Accordingly, as RCI_x increases, drawbar pull increases and motion resistance decreases for a given vehicle.

26. In some of the fine-grained dredged material containment areas described herein, the soil conditions were too soft to permit the extraction of soil samples for determination of the remolding index (RI). Since RI is used to determine RCI , the following means of obtaining RI values for these soft areas was devised. The remolding indexes available from all sites (Table A2) were grouped by soil type. Extremes in the data were deleted, and the indexes were then averaged to obtain the following average values:

Soil Type	No. of Samples Used for Averaging	Average Remolding Index (RI) 0- to 6-in. layer	Average Remolding Index (RI) 6- to 12-in. layer
CH	23	0.64	0.64
CL	3	0.58	0.61
MH	25	0.62	0.60
ML	6	0.39	0.41

Sandy soils (SM and SP) usually maintain or exceed their in situ strength after vehicle traffic. Consequently, no remolding tests were conducted for the sandy sites described herein, and the RI was merely assumed to be greater than 1.0 for this analysis.

Drawbar pull

27. Drawbar pull (D) is the amount of sustained force that a vehicle can develop under given operating conditions. Usually it is expressed in pounds or as a coefficient, D/W where W is the vehicle weight. D/W varies with track or wheel slip (S) for a given vehicle and operating condition (RCI_x). Usually maximum drawbar pull (D/W_{max}) occurs at 100-percent slip; however, at 100-percent slip, D/W_{max} is not a meaningful parameter because no useful work can be done when the vehicle is slipping in place with no forward movement. Usually an optimum D/W value occurs around 20-percent slip; therefore, this slip value represents the peak work output condition of the vehicle.

Motion resistance

28. Motion resistance (MR) is the force developed by the soil in resisting the movement of a vehicle; it is assumed to exhibit minimal variation with normal vehicle speeds but varies with RCI_x . MR usually is expressed as a coefficient (MR/W) or in pounds.

Tractive force

29. The total traction or tractive force (TF) generated by a vehicle is the sum of the drawbar pull (D) generated by the vehicle on RCI_x and the motion resistance (MR) created by the soil, or

$$TF = D + MR \tag{5}$$

The tractive force developed by the vehicle is relatively constant for a given vehicle speed, since D and MR vary in about the same degree, but oppositely for different soil strengths, i.e., as the soil strength increases, D increases while MR decreases, and as the soil strength decreases D decreases while MR increases. Consequently, the sum of D and MR is usually a relatively constant value for a given vehicle speed.

Soil strength

30. Generally, the relations developed by WES apply to soils that naturally exhibit profiles of increasing soil strength with increasing depth. In most cases, vehicle performance predictions for one pass (VCI_1) are based on the average of the cone penetrometer readings for

the 0- to 6-in. layer of soil. For heavy vehicles, however, this critical layer for one-pass vehicle mobility may be the 6- to 12-in. layer. For most vehicles either working (backhoes, draglines, etc.) or trafficking in a given soil condition, the critical layer is taken as the 6- to 12-in. layer.

31. In predicting vehicle performance in the nonhomogeneous soils sampled at the various CE Districts reported herein, the soil strength profiles were studied to a depth of 12 in. at each data site. The low soil strength measurements obtained for most sites generally occurred throughout the soil strength profile for the newly disposed sites and generally below 3 in. for the sites that had some surface crust. The trend of inverse soil strength profiles, i.e. weaker soils occurring below firmer surface soils, required analysis of both the 0- to 6-in. layer and the 6- to 12-in. layer and selection of the weaker of the two layers for performance predictions. Although somewhat conservative in some instances, this technique generally produced performance predictions reflective of expected field performance based on the soil conditions in each site. One pass of a vehicle over the soil conditions in each site would not necessarily disturb the 0- to 6-in. surface crust, but vehicles working in a site or making numerous passes over the surface would disturb or remold the upper layer and cause vehicle sinkage below the surface crust. Soil support for vehicle operations would then be required of the 6- to 12-in. layer, thereby making this layer critical in assessing the performance of the vehicle.

32. Table 1 was compiled from the soil strength measurements shown in Table A2 with the District locations coded as follows: Detroit District (DD); Chicago District (CD); New Orleans District (ND); Seattle District (SD); Philadelphia District (PD); Galveston District (GD); and Mobile District (MD). The weaker of either the 0- to 6-in. or the 6- to 12-in. layer was selected and reported in Table 1 for each data site in which cone penetrometer readings were collected. The values of CI and RCI shown in Table 1 were used for the performance predictions reported herein. Soil types, listed in Table 1, were used to ascertain if any analogies existing between soil strength and soil

type for the reported data. Based on these data, the clay soils, in most cases, exhibited the lowest RCI values, followed by the firmer silty soils; the firmest soils with the highest RCI values were usually sandy silt soils. However, further data collection is necessary to firmly establish or refute this trend.

Predictions of Vehicle Performance

Work functions

33. The concepts of the various jobs required of vehicles operating in and around dredged material containment facilities have progressed from earlier ideas alluded to in Reference 1. At the time of the vehicle inventory, it was anticipated that construction and reconnaissance vehicles with only a cargo-carrying capability (no on-board attachments for moving material) would be necessary for most operations. However, through field studies with the RUC[6] and observation of vehicle operations in the Mobile, Alabama, area, it now appears that the job assignments in and around dredged material containment facilities require vehicles that can also ditch or bulldoze or in some manner move or dispose of material inside the facilities. These material-moving operations are required to dewater the facilities, prepare the facilities for reuse through rapid consolidation of previously deposited material, or provide construction or maintenance services within the facilities.

34. In analyzing the work function of each vehicle relative to performance predictions in dredged material containment area operations, two general phases of operations require analysis: survey or reconnaissance activities and work or operational activities. The first phase is synonymous with visiting an area to survey field conditions, take soil or water samples, or perform some operation that requires only one pass over a specific area at any given time. The second phase is synonymous with moving material to create drainage paths for surface water, excavating ditches or sumps, or performing functions that require multiple passage by the vehicle in the same vehicle path. In this

operational environment, fine-grained soil under the vehicle is remolded with vehicle passage and becomes increasingly weaker relative to the in situ strength. Although operations wherein supplementary support is used, such as wood mats, require soil strengths between those required for the two phases described above, these operations will be considered as Phase 2 operations in this analysis, with the understanding that performance predictions, in most cases, will be somewhat conservative.

Soil data

35. The soils data were collected for this analysis using procedures that would ensure that the dredged material containment areas that were visited and sampled were as representative as possible within each CE District. District personnel were asked to select containment areas representative of areas within their jurisdiction and as many sites as possible within time restrictions were sampled within the containment area. Although the sampled areas described herein will consolidate with time, the fact that most of the material used to fill the areas was generally dredged during periodic maintenance dredging should ensure a relatively constant number of areas similar to those sampled and reported herein. The data thus collected are considered representative and will be discussed accordingly.

Vehicles

36. The catalog[1] of low-ground-pressure vehicles did not include predictions relative to operational capacities or production, but instead, reported on investigated anticipated performance on a go-no go basis and estimated the drawbar pull of the inventoried vehicles. To perform activities such as those described previously (paragraphs 33 and 35), the vehicles to be analyzed herein were grouped relative to their anticipated function in dredged material containment area operations: trenching, earthmoving, or survey and reconnaissance. Within each of these basic categories, vehicles were selected for analysis from the catalog inventory and supplemented with representative construction equipment generally characterized as low-ground-pressure vehicles. Using the soil strength data collected in this study, performance was predicted relative to the three functions or work groups, based on

performance in a percentage of the areas visited and cataloged in this analysis. To assist in preparing these predictions, the critical layer RCI values in terms of percentage of sampled areas with RCI or CI greater than each strength value measured were plotted from the data in Table 1 and are shown in Figure 3.

37. The following representative vehicles were selected for study in this analysis, relative to their expected work functions in dredged material containment area operations.

Vehicle	Model or Type	Work Function
1. Amphicat	-	Survey and reconnaissance
2. Thiokol-Trackmaster	601	Survey and reconnaissance
3. Thiokol Spryte	1201	Survey and reconnaissance
4. M29C Weasel	U. S. Army	Survey and reconnaissance
5. MTV (marginal terrain vehicle, XM759)	U. S. Army	Survey and reconnaissance
6. Marsh Screw Amphibian	-	Trenching and survey
7. Quality marsh equipment ditcher	104T-DSP-70	Trenching
8. Riverine Utility Craft (RUC)	-	Trenching
9. Quality marsh equipment dragline	10XT-DSP-70	Trenching and earthmoving
10. Caterpillar dozer	D4DLGP (low-ground-pressure)	Earthmoving
11. Caterpillar dozer	D5LGP (low-ground-pressure)	Earthmoving
12. John Deere dozer	350C (wide track)	Earthmoving
13. J. I. Case dozer	350HF (wide track)	Earthmoving
14. International Harvester dozer	IH500E	Earthmoving
15. P&H dragline/crane/shovel	315	Trenching and earthmoving

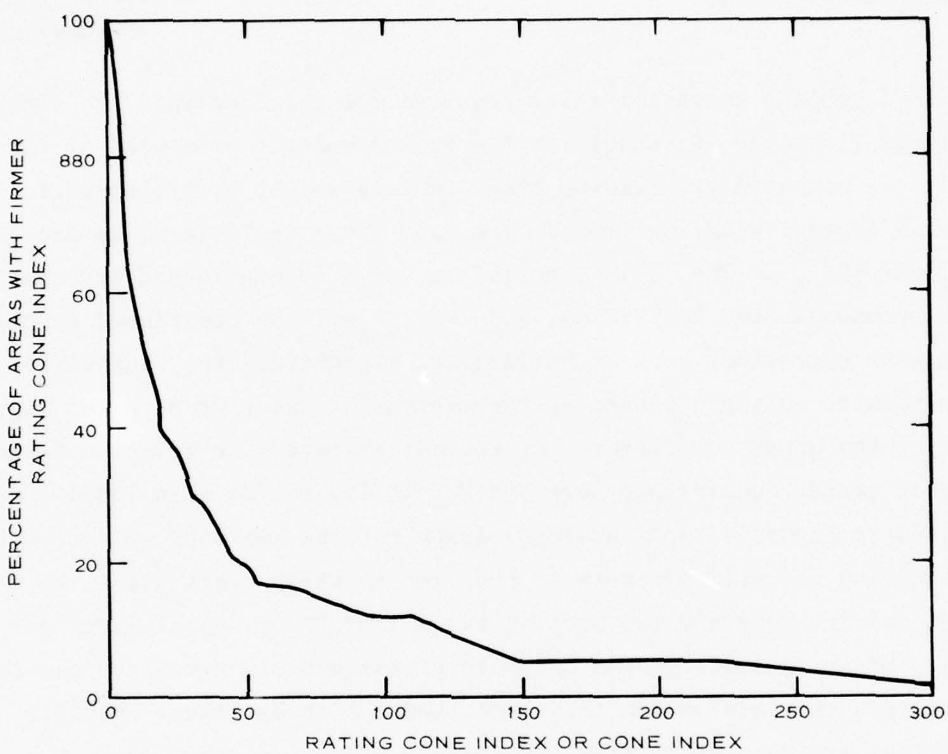


Figure 3. Soil strength occurrence versus strength for all areas sampled

Vehicle	Model or Type	Work Function
16. Liebherr "Swamper" dragline/ crane/shovel	925	Trenching and earthmoving
17. Bucyrus Erie dragline	15B	Trenching and earthmoving
18. Bantam excavator	C451	Trenching and earthmoving

38. Vehicle characteristics required for this analysis are shown in Table 2 for the 18 vehicles. The ground contact pressures of the vehicles, computed by dividing gross vehicle weight by projected surface area in contact with the ground, are also shown in Table 2, as are the VCI_1 and VCI_{50}. The VCI_1, hereafter, will be considered synonymous with reconnaissance activities, and VCI_{50} will be considered synonymous with operations such as bulldozing, trenching, etc., activities that require multiple passes by the vehicle in the same path and degradation of the upper soil layer. As an indication of the relation between vehicle ground contact pressure and VCI (RCI), the data in Table 2 were plotted in Figure 4, and envelopes drawn for the two sets of data. By determining the soil strength in the area in which tests are to be conducted and entering the plot at the RCI of the critical layer for the area, the approximate ground pressure of the vehicle necessary for the required work function can be ascertained. Although these specific relations are only predictive and were based on available data, the supporting data from which these relations were constructed have been validated through years of vehicle testing. Future field testing relative to the data in Figure 4 may produce results that require revision of these curves, but for the present predictive purposes, they appear adequate.

Predicted vehicle performance

39. The 18 vehicles shown in paragraph 37 represent a wide spectrum of vehicles with various propulsion systems and a range of vehicle weights and sizes. To evaluate their expected performance on a go-no go basis in dredged material containment areas, the soil strength data

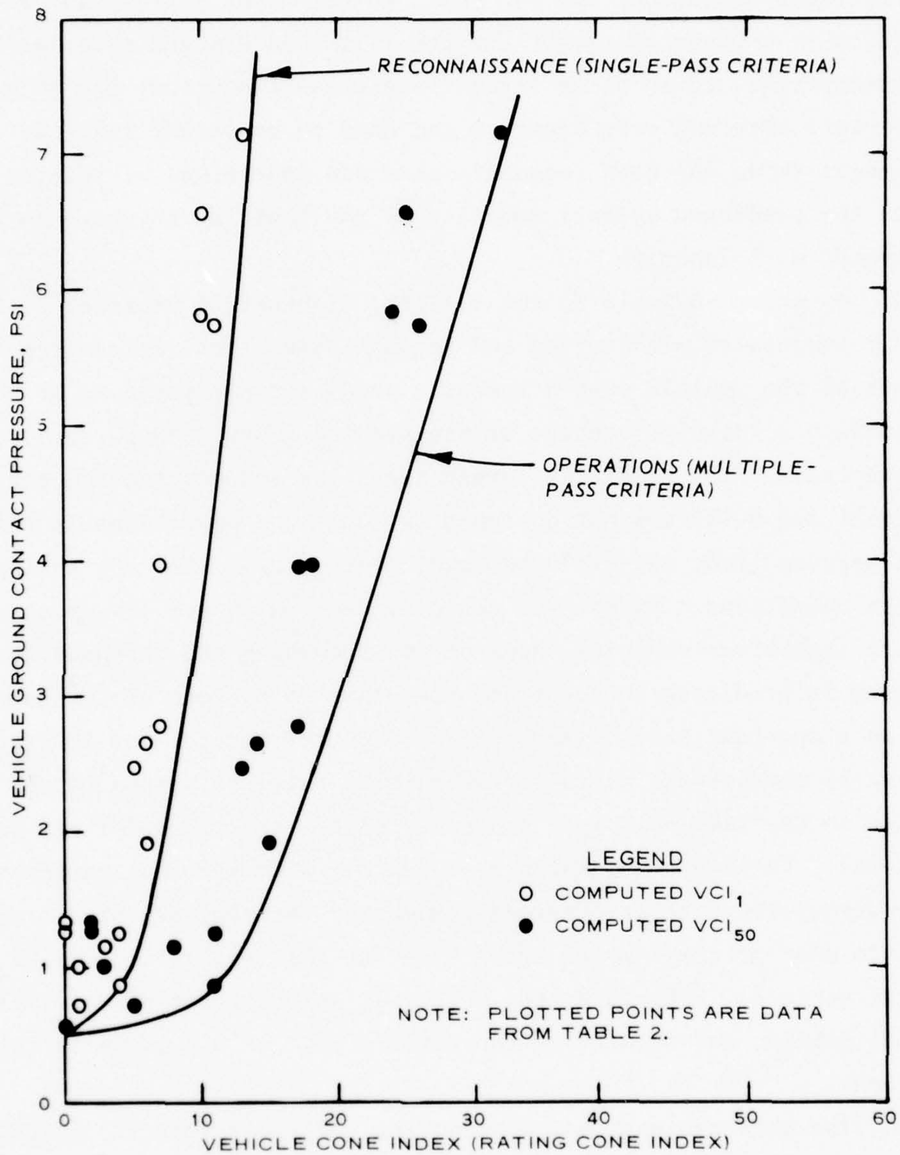


Figure 4. Plot of vehicle ground contact pressure as a function of soil strength

plotted in Figure 3 were used. Using the VCI_1 to represent one-pass criteria (reconnaissance) and the VCI_{50} to represent fifty-pass criteria (operations), the percentage of the total sampled dredged material containment areas equal to or firmer than these two values for each vehicle were obtained from Figure 3 and used to construct Table 3. The percentages shown for both reconnaissance and operations activities reflect the predicted overall mobility of the vehicles relative to their anticipated work function.

40. As shown in Table 3, the smaller, lightweight vehicles (1-5) commonly associated with survey and reconnaissance activities (requiring one pass of the vehicle over a specific area) are predicted to be able to negotiate a large percentage of the sampled areas (>70 percent) on a one-pass basis. The generally larger trenching and earthmoving equipment (vehicles 6-18) are not designed for one-pass operations in soft, marshy terrain (root mat excluded) and, consequently, are not equipped for such operations. Except for vehicles 6-9, which are low-ground-pressure amphibious vehicles, none of the trenching and earthmoving equipment is predicted to negotiate more than 75 percent of the sampled areas on a one-pass basis. The predicted performance of the 18 vehicles relative to operational activities requiring multiple passes by the vehicles in the same soil area generally follow the trend for one-pass operations. Vehicles 6-9, which are vehicles with somewhat unconventional propulsion systems designed for marshy terrain, are predicted to negotiate most of the sampled areas used for this analysis. One of this group of vehicles, vehicle 8 (the RUC), was selected for more detailed study at Mobile, and results of these tests will be discussed in later paragraphs.

41. The more conventional earthmoving equipment (dozers, draglines, etc.) could not operate in a majority of the areas sampled because of the combination of extremely soft soils and high vehicle ground pressures. However, these vehicles, or vehicles of these types, must be used where substantial amounts of material will be moved by mechanical means or where large towing forces must be developed for towing equipment (drill rigs, soil samplers, etc.) inside the dredged material

containment facility in operational activities (multiple passes). Relations have been developed by WES to predict the performance of these vehicles moving material or towing equipment in fine-grained soils (coarse-grained soils usually present few operational problems). These curves, shown in Figures 5 and 6 for tracked and wheeled vehicles, respectively, are based on excess rating cone index above either VCI_1 or VCI_{50} to correlate with previously described data. Curves are shown for vehicles with ground pressures ≤ 4 psi and > 4 psi, the ground pressure found through research by WES to generally produce a change in vehicle performance. Although the VCI_1 curves presently appear only minor in consequence when specific work functions are considered, the predictive data represented by these curves will be included herein for future reference. Relative to either reconnaissance or the more important operational activities, however, the available drawbar pull of a vehicle can be estimated from the figures, based on excess RCI above VCI, by estimating the soil strength in the area where operations are scheduled. The predicted drawbar pull of the vehicle can then be used to estimate force available for moving material in the area in earthmoving, trenching, scraping, or similar operations. Use of force estimates will be discussed in later paragraphs.

Auxiliary Trenching Equipment

42. Because of the long time interval between initial disposal into a new area and the point at which sufficient crust thickness forms in an area to allow traffic by heavier, more conventional equipment, any operations that can aid in removal of decanted water or rainwater will speed desiccation. Also, the semifluid, soupy material existing in the areas during this interval allows passage of only the lowest-ground-pressure vehicles (ground pressures <1 psi), which usually must be amphibious. These vehicles usually are not conventional dozers or ditchers and most lack means of moving material or creating drainage paths to drain surface water and speed crust formation. Consequently, auxiliary equipment that can trench or ditch while being towed by these

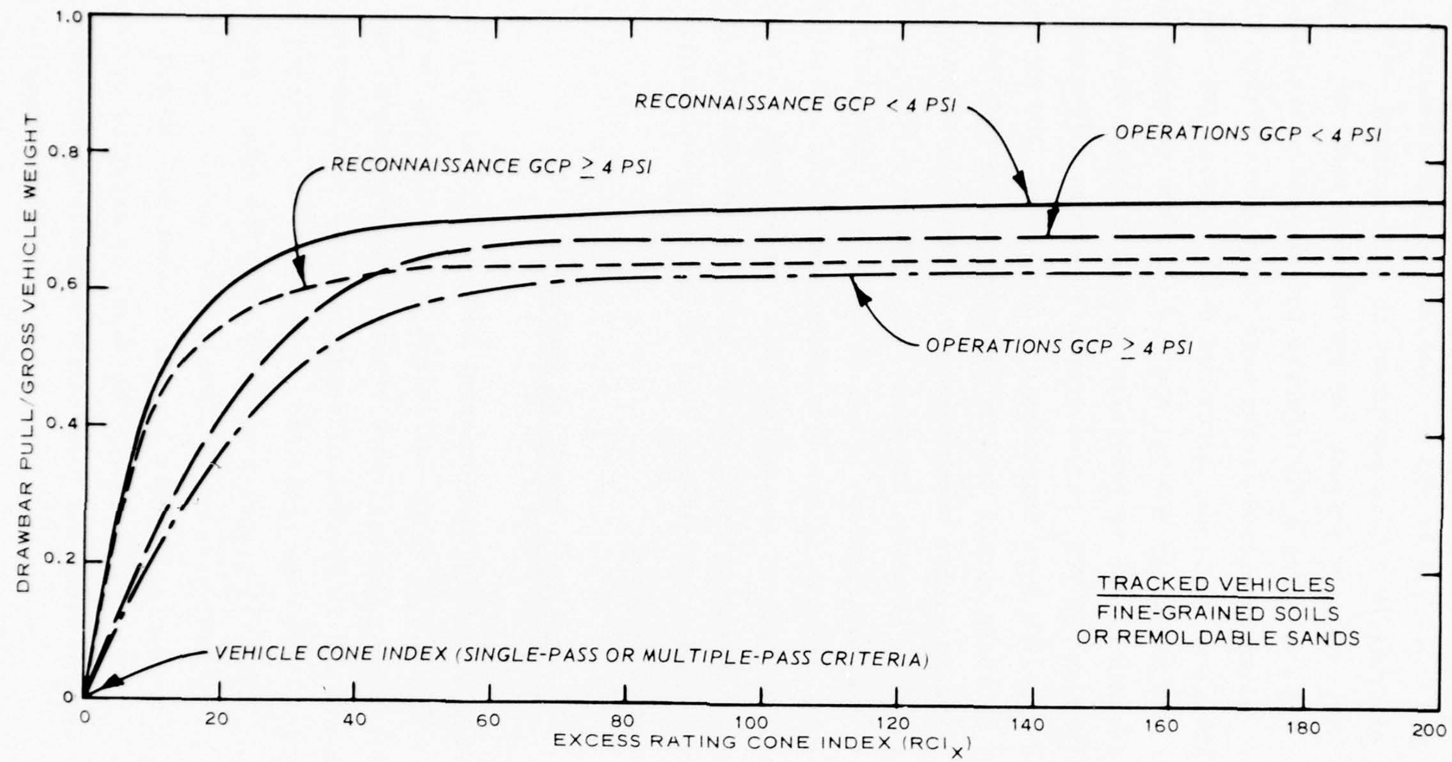


Figure 5. Drawbar pull versus soil strength for tracked vehicles

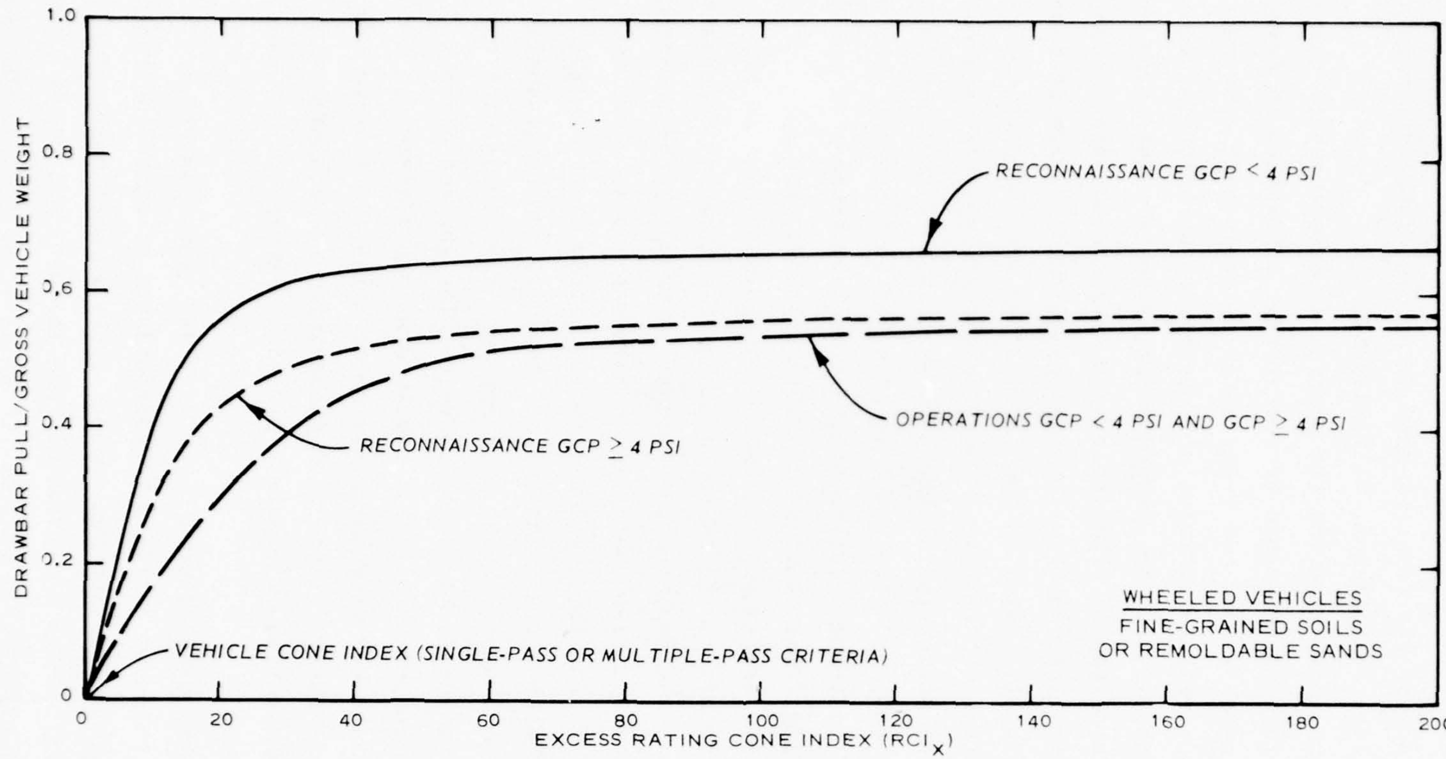


Figure 6. Drawbar pull versus soil strength for wheeled vehicles

vehicles will assist in dewatering efforts or actually improve the performance of any of the vehicles that do possess onboard trenching or ditching capability (vehicles 5, 6, 7, and 8).

43. As a means of improving the predicted performance of the 18 vehicles above in reconnaissance or operational activities in dredged material containment areas, two towed ditching tools were constructed to allow low-ground-pressure vehicles without blades or trenching equipment to provide useful services in dredged material containment areas by merely towing these tools. The tools were constructed using ideas obtained from existing construction and agricultural equipment sources, but were not actually tested in the field. Two sets of each tool were constructed so that the tool sets could be towed singly or as a pair, either behind the centerline of the vehicle or with a tool set in each rut made by the vehicle. It is not anticipated at this time that one of each tool would be towed together behind a vehicle because of the differences in towing force required to pull each tool type.

44. Two large sealed wheels, each like the one shown in Figure 7a, were constructed to be towed behind the vehicles to create V-shaped ditches, the depth of the ditches governed by the strength of the material in the dredged material containment areas. Each wheel, approximately 4 ft in diameter and 1 ft in maximum width, weighed approximately 275 lb empty. The weight, however, can be gradually increased to a maximum of 550 lb each for very firm soils with the addition of water inside the sealed wheels. The surface ditches formed by towing the V-shaped wheels will create drainage patterns in the relatively flat dredged material containment areas, increasing the volume of surface water (either from decantation or rainfall) that can be removed from the area, ultimately creating a surface crust over most or all of the area.

45. Two pairs of 4-ft-diam circular disks, shown in Figure 7b, were also fabricated to increase the performance of nonbulldozing or nonexcavating vehicles. The two opposed disks in each pair, of 6-in. maximum concavity, weigh approximately 200 lb total and can be used to ditch and throw aside soil, usually firmer material such as that existing

a. Towable V-shaped wheel

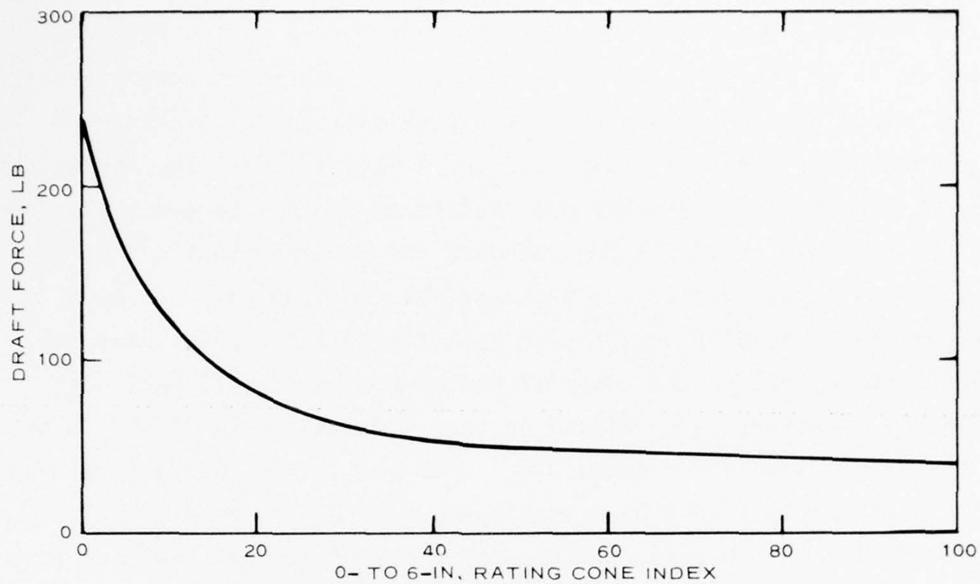
b. Towable disk pair

Figure 7. Auxiliary trenching equipment

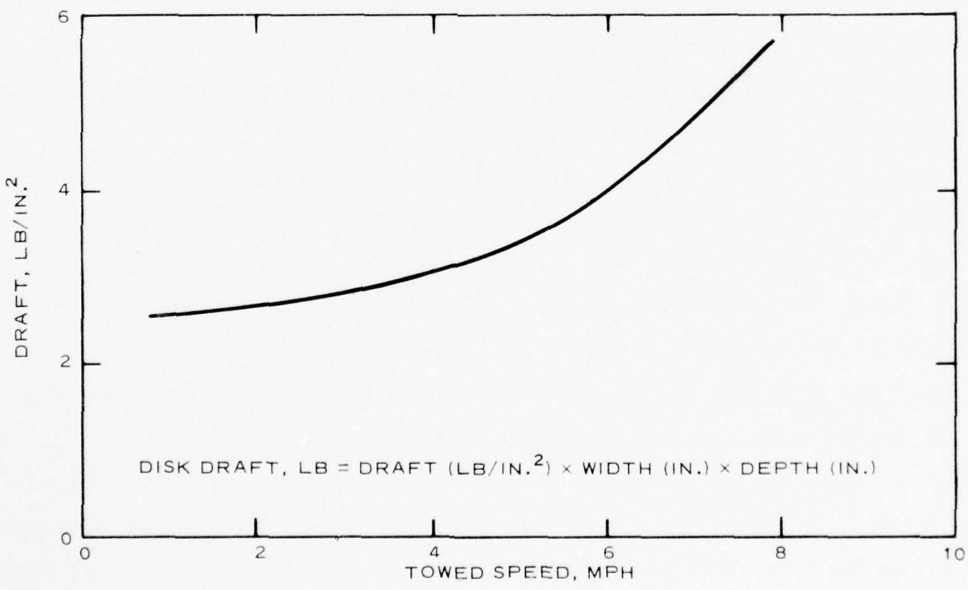
after formation of a slight surface crust. The depth of the ditches created will again be a function of the soil strengths in the dredged material containment areas. The maximum width of a pair of disks in the towed direction is 39 in.

46. To ascertain the amount of predicted drawbar pull required to tow the two implements in the dredged material containment areas described herein, the towing force required by each set of wheels or disks was estimated from draft curves obtained from agricultural interests[3] supplemented with data for similar devices tested previously by the WES.[4] These force data represent tests in rather firm, homogeneous soils, however, and the curves constructed from these data and shown in Figure 8 will require validation in dredged material containment areas, as will the other prediction curves described previously. The predicted forces for these implements represent only average force values, in that specific depths of operation and implement widths are required to compute the draft force. These dimensions, however, are seldom constant in field operations, and the heterogeneity of most dredged material containment areas, relative to soil strengths and surface crusts, requires averaging of the environmental factors present in order to predict average single towing force or draft requirements.

47. Although the curves presented in paragraphs 40-46 have not been validated through field testing, the data on which they are based have been validated by WES through years of soil-vehicle testing. Consequently, the curves should represent the expected performance of vehicles or vehicle-tool combinations in field operations in dredged material containment areas and should need only minor revision through field testing to become valid predictive devices. As an example of the use of these curves in determining whether vehicles or vehicle-tool combinations will perform in designated dredged material containment areas, the data shown in Table 4 were computed from the curves discussed in paragraphs 40-46. In order to compute the drawbar pull values for Table 4, a soil strength value of 20 RCI was selected from Figure 3 to represent a majority (≈ 60 percent) of the areas sampled for this analysis.



a. TOWING FORCE REQUIREMENTS, V-SHAPED WHEEL



b. TOWING FORCE REQUIREMENTS, DISK PAIR

Figure 8. Predicted towing force requirements for auxiliary trenching equipment

48. Using Figure 8a, the draft force required to tow the V-shaped wheel on 20 RCI would be 80 lb. Assuming a 2-mph towed speed with 12 in. width and 12 in. depth for the disk set, Figure 8b yields a required towing force of 3 psi × 12 in. × 12 in. or 432 lb. Using these values, the available drawbar pull values of Table 4 exceed either 80 lb for the V-shaped or 432 lb for the disk and indicate that all of the vehicles will pull either one V-shaped wheel or one disk set on a 20 RCI for one pass. Even if two of each tool are pulled together and the pulls doubled, all of the vehicles except vehicle 1 will pull both. Vehicle 1, however, is predicted to have a drawbar pull of 509 lb on 20 RCI. Two disk sets require 2 × 432 or 864 lb, or 355 lb more drawbar pull than Vehicle 1 will have available on 20 RCI. The drawbar pull available for multiple passes is not sufficient for all vehicles to tow equipment on 20 RCI. Vehicles 15-18, with VCI_{50} values greater than 20 RCI, will not be able to negotiate 50 passes alone and, consequently, will not be able to tow any equipment in multiple passes on 20 RCI. Most of the remaining 14 vehicles (except vehicle 1) are predicted to develop sufficient drawbar pull above VCI_{50} to tow one of each tool. All of the 14 vehicles except 1, 4, 10, and 13 are predicted to develop sufficient pull to tow two of each tool.

49. Although this illustration includes some vehicle-tool combinations that may seem somewhat unlikely to be used together in a real field investigation, nonetheless the illustration shows the use of the prediction curves in assessing vehicles or vehicle-tool combinations in operations in dredged material containment areas. The available drawbar pull predicted with Figures 5 and 6 may also be used for additional vehicle predictions, such as earthmoving production in terms of quantity of material bulldozed or excavated per hour. The soft soils sampled for this analysis would preclude any large amounts of earthmoving or excavation, but future investigations, in dredged material containment areas that have been dormant for several years and where soil strengths are much higher, may indicate that such efforts could be useful. If so, techniques have been developed to use the data in Figures 5 and 6 to determine anticipated production.[7]

RUC Operations

50. Only the Riverine Utility Craft (RUC), vehicle 8, (Figure 9a) was predicted to negotiate all of the sampled areas described herein (Table 3). This particular vehicle, now undergoing extensive field testing at Mobile, is a unique and specialized piece of equipment. By nature of its propulsion system (the Archimedes screw principle), the RUC can rather easily create concave ditches from 6 in. up to 3 ft deep by 3 ft wide depending on crust thickness in most dredged material containment areas (Figure 9b) to serve to drain or dewater the areas (Figure 10a). The RUC also has an extremely high horsepower-to-weight ratio (156 hp/ton), 2 to 5 times higher than most vehicles, and is amphibious, both factors ensuring that the vehicle will traverse most dredged material containment areas from the initial fluid state up to the very stiff, crusted, vegetated state resulting from natural desiccation.

51. To obtain a data base for evaluating the effectiveness of dewatering techniques with the RUC, a full-scale test program was undertaken at Mobile, Alabama, in August 1975. Although the full report of the findings of this program will be published separately, some results to date bear mentioning herein.

52. The RUC is capable of negotiating in almost any soil condition, although the extremely high coefficient of friction between the rotors and dry sand, such as occurs near dredge pipe outfalls, places a severe strain on the gears and transmissions. Several breakdowns have occurred at Mobile because of this severe strain in areas of dry sand. Also, there exists an optimum soil strength (30 RCI) in fine-grained soils with surface crusts, in which the RUC is capable of creating relatively smooth 16- to 24-in.-wide ruts with a single pass of the vehicle (Figure 9). These trenches serve to remove surface water from rainfall or decantation, with the water draining through desiccation cracks to the ruts, and down the ruts to outflow wiers (Figure 10a). The resulting crust, formed by natural evaporative processes, however, soon thickens so that it extends below the bottom of the RUC trenches, and drainage

a. Riverine Utility Craft (RUC)

b. RUC ruts in RCI ≈ 30 to serve as surface drainage media

Figure 9. Riverine Utility Craft (RUC) and ruts in soil with RCI ≈ 30

a. RUC tracks used as surface drainage media

b. Marsh dragline increasing depths and widths of RUC tracks

c. Small dragline on mats increasing depths and widths of dragline ditches

Figure 10. Progressive trenching techniques in dredging material containment area dewatering

becomes less efficient. Thus, progressive trenching, i.e., increasing trench depth with periodic RUC operations, is necessary to maintain a trench flow line below the base of adjacent desiccation cracks. Also, periodic trenching is necessary because the fluid state of dredged material under the crust inhibits the establishment of trench depths more than a few inches below existing crust thickness. Eventually, the surface crust over the area formed through this periodic trenching process becomes too thick and the trench depths too deep for the RUC to operate effectively. However, at this point in time, the surface crust is usually thick enough to support first amphibious draglines and later either small draglines or backhoes to operate in the area to progressively deepen the trenches, as shown in Figures 10b and 10c.

53. In dewatering a dredged material containment area with the RUC, the initial step is to break up any crusted or heaped material immediately in front of and adjoining the drainage paths constructed in the dikes (sluices, weirs, culverts, etc.)(Figure 11a), preferably following completion of the pumping operations. Some slight depressions will occur behind the RUC, which will immediately fill with decanted water (Figure 11b). After several weeks of periodic operations of the RUC, usually in established ruts from previous operations, sufficient crust will form to allow ditches to form following passage of the RUC. With continued RUC operation and consequent desiccation, the RUC trenches will increase in depth (Figure 10b), and the soil will finally reach a consistency of about 30 RCI, in which nearly semicircular, relatively smooth ditches can be created. From this point on, progressive trenching techniques can be used to deepen and widen the ditches to remove rainwater while allowing the area to dessicate.

54. The complete RUC dewatering operation, depending on the size of the area, soil conditions, and climate may take from several months to a year before sufficient crust has formed to allow more conventional vehicles onto the crust in the area. In most climates, the rainy season will interrupt this cycle (for a given area), and without management of the drainage structures the area may again fill with surface water. To maintain drainage over this period, several techni-

a. RUC agitation of crust material near weirs

b. RUC ruts in near-fluid soil immediately after pumping operation ceased

Figure 11. Dewatering techniques using RUC ruts for drainage

c. Progressive trenching, including finger trenches

d. Mobile area immediately after RUC operations

e. Mobile area one week after RUC operations

Figure 11 (Concluded)

ques were attempted with the RUC, but the most effective appeared to be finger trenches (Figure 11c), which radiated out into the disposal area from the weirs and provided drainage paths throughout the area. Other techniques are now being attempted and will be reported in future reports on Mobile tests. This step-by-step process has been used thus far at Mobile, Alabama, and Charleston, South Carolina, with outstanding results. In Mobile some 50 acre-ft of water were removed from a dredged material containment area in 24 hr using RUC trenches; the area drained to the point where only 20 to 30 acre-ft of water remained in the area one week later (Figures 11d and 11e).

55. The uniqueness of the RUC and its military background prohibits easy procurement of RUC-type vehicles for Corps-wide use. At present, no large RUC-type vehicle is commercially available on the open market.

56. Further testing at Mobile will provide additional information relative to RUC operations, dewatering techniques, vehicle evaluations, etc., and should lead to development of an orderly process of dredged material containment area dewatering and desiccation using RUC-type vehicles.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

57. Based on the analysis of the data obtained for this study, the following conclusions are drawn:

- a. Based on data obtained by this investigation, soil-vehicle relations derived by WES appear to be applicable to vehicle operations in dredged material containment areas even though the cone index-depth profiles are reversed, i.e., the material usually weakens with depth rather than strengthens. Therefore, vehicle performance relations that are known to be valid for normal cone-index-depth profiles should be valid for dredged material containment area operations.

- b. Soil data collected in 45 confined dredged material disposal areas in six Corps of Engineer Districts indicate that soft soils are much more prevalent than firm soils, with nearly 80 percent of the areas exhibiting critical-layer soil strengths less than 50 RCI. This high percentage of areas with relatively soft soils indicates that only vehicles with very low ground contact pressures will be able to negotiate most CE dredged material containment areas.

- c. Three basic work functions appear necessary in operations in dredged material containment areas: survey and reconnaissance, trenching, and earthmoving. At present, only survey and reconnaissance vehicles appear available to any limited extent.

- d. Based on the vehicle analysis in this study, only unique or specialized equipment, specifically designed for soft-soil operations, are capable of negotiating more than 95 percent of the areas sampled and perform functions other than survey and reconnaissance. Many of the smaller lightweight vehicles are capable of making single passes over these areas, but are not capable of performing any work functions.

- e. Conventional trenching or earthmoving equipment capable of moving material in these areas to create ditches, move dredged material, or build cross-dikes, require firm soil on which to perform such activities and consequently are predicted to negotiate only about 50 percent of the areas sampled. These vehicles are seldom required to perform their assigned functions in soft, marshy terrain and are not designed for such activities.

f. Although not tested in a field environment, two towed ditching and trenching implements fabricated for soft-soil operations could assist vehicles without on-board trenching equipment in dewatering selected dredged material containment areas on a limited basis.

g. Field tests to date indicate that the RUC bridges the transitional zone in dredged material containment area development from the fluid state to the semisolid state; during this desiccation process, the RUC is capable of performing useful functions relative to dewatering and consolidating the area. RUC operations appear to be a useful initial step in dewatering of the area, and by using progressive trenching techniques, sufficient water can be removed in the area to permit the formation of crust sufficient to support progressively heavier trenching or earthmoving equipment.

Recommendations

58. Based on the above conclusions, it is recommended that:

a. Carefully monitored tests be conducted in dredged material containment areas to validate extrapolated WES soil-vehicle relations.

b. Tests be conducted with as many types of vehicles as possible to verify the three work functions to ascertain if all are practical or if more functions should be added.

c. Monitor crust formation in the Mobile area to determine the point at which conventional equipment can enter the area.

d. Tests be conducted with the two towed implements to validate the predicted drag force curves shown in this report. Also, tests should be conducted to determine other parameters that affect the utility of the implements to determine the proper soil conditions, towing speeds, etc., for optimum implement effectiveness.

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Table 1

Critical Layer Values of RCI or CI for Data Sites*

Location Code**	RCI or CI	Soil Type
DD-1-1	0	CH
DD-1-4	0	CH
ND-9-1	0	SM
GD-5-1	1	CL
PD-3-1	1	MH
GD-9-1	2	CH
GD-12-1	2	CH
GD-12-3	2	CH
PD-1-1	2	MH
DD-3-4	3	MH
MD-1-3	3	CH
MD-1-4	3	CH
GD-4-1	3	CL
PD-6-3	3	MH
DD-5-3	3	CH
DD-1-3	3	CH
DD-1-5	3	CH
MD-2-1	3	CH
DD-5-2	4	CH
PD-6-1	4	MH
GD-12-2	4	CH
DD-1-2	4	CH
SD-2-1	4	OL
MD-1-2	4	CH
PD-1-2	4	MH
DD-3-3	4	MH
GD-7-1	5	CL
CD-3-2	5	MH
GD-11-1	5	CH
SD-5-3	5	ML
SD-6-2	5	ML
SD-6-1	6	ML
CD-1-3	6	ML
GD-1-2	6	CH
SD-2-2	6	OL

(Continued)

* Data shown are for those sites where data could be collected. For those too soft for collecting, the RCI and CI would be 0.

** See paragraph 79.

Table 1 (Continued)

Location Code**	RCI or CI	Soil Type
MD-2-2	6	CH
GD-6-1	7	CL
SD-3-1	7	OL
SD-3-2	7	OL
MD-1-1	7	CH
CD-3-5	8	MH
CD-3-6	8	MH
CD-1-2	9	ML
GD-6-2	9	CL
CD-1-6	10	ML
DD-3-2	10	MH
GD-3-3	11	CH
DD-4-2	12	CH
CD-2-4	12	MH
GD-10-1	12	CH
PD-2-2	12	MH
DD-5-1	13	CH
GD-13-1	13	CH
GD-3-2	14	CH
DD-4-1	15	CH
CD-1-1	15	ML
PD-4-1	16	ML
DD-3-1	20	MH
ND-9-2	>21	SM
PD-3-2	21	MH
ND-4-2	21	CH
ND-5-1	22	CH
CD-1-5	24	ML
DD-2-3	24	MH
GD-3-1	24	CH
CD-1-4	25	ML
PD-7-1	25	MH
DD-2-4	28	MH
PD-2-1	30	MH
CD-2-1	31	MH
CD-3-3	31	MH
CD-3-4	31	MH
GD-1-3	31	CH
CD-3-1	32	MH
SD-5-1	32	ML

(Continued) (Sheet 2 of 3)

Table 1 (Concluded)

Location Code**	RCI or CI	Soil Type
DD-5-1	35	MH
DD-4-3	38	CH
GD-11-2	38	CH
DD-2-5	40	MH
DD-2-1	43	MH
SD-5-2	>43	SM
DD-2-2	46	MH
DD-4-4	53	MH
GD-2-1	53	CH
PD-2-3	53	ML
PD-1-3	58	ML
PD-5-2	61	MH
PD-2-4	73	ML
CD-2-3	>79	SM
CD-2-2	>89	SM
DD-4-5	96	SM
ND-3-1	>110	ML
ND-9-3	>116	SM
PD-6-4	>121	SM
PD-7-3	137	MH
ND-4-1	>138	SM
SD-4-1	>139	SP
ND-10-1	>145	SM
ND-1-1	>220	SP
ND-2-1	>221	SP
ND-5-2	>257	SM
PD-7-2	>269	SM
PD-6-2	>302	SM

(Sheet 3 of 3)

Table 2

Vehicle Characteristics

Vehicle* No.	Vehicle* Description	Gross Vehicle Weight lb	Tire or Track Width in.*	Track Length in Contact Ground in.**	No. of Support Rollers in Contact with Ground	Ground Clearance in.	Gross Horse-power	Ground Contact Pressure psi	VCI_1	VCI_{50}
1	Amphicat	925	11.5	38.6	NA	8.0	16	1.04	1	3
2	Thiokol Trachmaster	5,500	32.0	99.0	8	13.5	138	0.87	4	11
3	Thiokol Spryte	8,080	36.0	98.0	10	11.0	170	1.15	3	8
4	M29C	6,000	20.0	78.5	8	11.0	65	1.91	6	15
5	MTV	10,000	21.0	190.0	10	33.0	160	1.25	4	11
6	Marsh Scrow Amphibian	3,954	26.0	106.0	NA	20.0	116	0.72	1	5
7	Quality Marsh Ditcher	23,500	48.0	190.0	8	38.0	120	1.29	0	2
8	RUC	10,000	39.0	216.0	NA	49.0	760	0.59	0	0
9	Quality Marsh Dragline	32,000	60.0	204.0	8	38.0	82	1.31	0	2
10	Cat D4DLGP	20,800	30.0	87.0	12	14.0	75	3.98	7	18
11	Cat D5LGP	30,000	34.0	111.0	14	12.0	105	3.97	7	17
12	John Deere 350 CWT	12,050	33.0	69.0	10	13.0	46	2.65	6	14
13	Case 350 HF	9,127	36.0	63.0	10	11.0	44	2.79	7	17
14	IH500E WT	10,720	32.0	68.0	10	13.0	42	2.46	5	13
15	P&H 315	45,000	30.0	114.0	16	20.0	90	6.58	10	25
16	Liebherr 925	45,000	30.0	129.0	16	21.0	100	5.81	10	24
17	Bucgrus Erie 15B	31,000	20.0	108.0	14	13.0	95	7.18	13	32
18	Bantam C451	33,000	24.0	120.0	14	13.0	108	5.73	11	26

* Rotor width or tire width projected to ground contact.
** Rotor dimensions or tire dimensions projected to ground contact.

Table 3

Percentage of Areas Negotiable for Reconnaissance and Operational Activities

Vehicle No.	Vehicle Description	VCI_1	VCI_{50}	Percentage of Areas Negotiable for 50 Passes (Reconnaissance)	Percentage of Areas Negotiable for 50 Passes (Operations)
1	Amphicat	1	3	97	91
2	Thiokol Trachmaster	4	11	83	55
3	Thiokol Spryte	3	8	91	61
4	M29C	6	15	70	48
5	MTV	4	11	83	55
6	Marsh Screw Amphibian	1	5	97	75
7	Quality Marsh Ditcher	0	2	100	95
8	RUC	0	0	100	100
9	Quality Marsh Dragline	0	2	100	95
10	Cat D4DLGP	7	18	65	45
11	Cat D5LGP	7	17	65	45
12	John Deere 350 CWT	6	14	70	49
13	Cast 350 HF	7	17	65	45
14	IH500E WT	5	13	75	50
15	P&H 315	10	25	57	37
16	Liebherr 925	10	24	57	40
17	Bucgrus Erie 15B	13	32	50	29
18	Bantam C451	11	26	55	35

Table 4

Computations of Available Vehicle Drawbar Pull on 20 RCI

Vehicle No.	Vehicle Description	VCI_1	VCI_{50}	Excess RCI Above VCI_1	Excess RCI Above VCI_{50}	Drawbar Pull Available for One Pass, lb	Drawbar Pull Available for 50 Passes, lb
1	Amphicat	1	3	19	17	509	241
2	Thiokol Trachmaster	4	11	16	9	3025	1155
3	Thiokol Spryte	3	8	17	12	4606	2182
4	M29C	6	15	14	5	3120	720
5	MTV	4	11	16	9	5500	2100
6	Marsh Screw Amphibian	1	5	19	15	2332	1305
7	Quality Marsh Ditcher	0	2	20	18	14100	8930
8	RUC	0	0	20	20	6000	4200
9	Quality Marsh Dragline	0	2	20	18	19200	12160
10	Cat D4DLGP	7	18	13	2	10608	832
11	Cat D5LGP	7	17	13	3	15300	2100
12	John Deere 350 CWT	6	14	14	6	6266	1687
13	Case 350 HF	7	17	13	3	4655	639
14	IH500E WT	5	13	15	7	5789	1715
15	P&H 315	10	25	10	-	18900	NO GO
16	Liebherr 925	10	24	10	-	13020	NO GO
17	Bucgrus Erie 15B	13	32	7	-	10560	NO GO
18	Bantam C451	11	26	9	-	13200	NO GO

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Willoughby, William E
  Low-ground-pressure construction equipment for use in dredged material containment area operation and maintenance: Performance predictions / by William E. Willoughby. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.
  46 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-7)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit 2C09B.
  ~~Appendix A on microfiche in pocket.~~
  References: p. 46.

1. Consolidation. 2. Construction equipment. 3. Containment areas. 4. Dewatering. 5. Dredged material disposal. 6. Off-road mobility. 7. Off-road vehicles. 8. Performance predictions. 9. Riverine utility craft. 10. Soft soils. 11. Soil-vehicle interaction. 12. Trafficability prediction. 13. Vehicle performance. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-7.
TA7.W34 no.D-77-7

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-7

LOW-GROUND-PRESSURE CONSTRUCTION EQUIPMENT FOR USE IN DREDGED MATERIAL CONTAINMENT AREA OPERATION AND MAINTENANCE: PERFORMANCE PREDICTIONS

by

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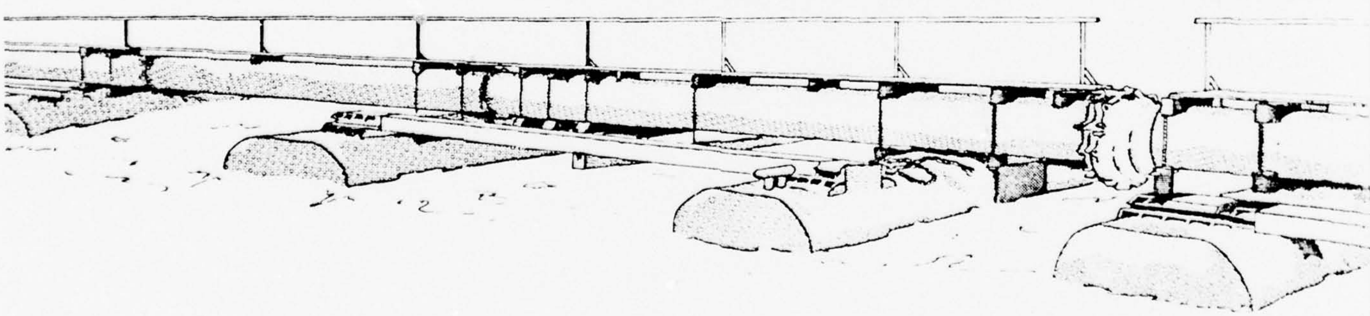
P. O. Box 631, Vicksburg, Miss. 39180

August 1977

Final Report

Approved For Public Release; Distribution Unlimited



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APPENDIX A: DATA SUMMARY AND SITE DESCRIPTION FOR SAMPLED CONTAINMENT AREAS

1. The representative dredged material containment areas visited in this study are described and the operational environments are discussed in the following paragraphs. Basic cone index data are listed in Table A1 and soils data are summarized in Table A2. The data described herein, by nature of the selection and collection procedures, are considered representative of most CE Districts within the contiguous United States.

Detroit District areas

2. Two areas near Lincoln Park, Michigan, (Figure A1) were visited in May 1975, but were not sampled because of their inaccessibility. The two unsampled areas, Mud Island and Grassy Island in the Detroit River, were islands formerly diked to serve as containment facilities. Four areas (1, 2, 4, and 5) in the Maumee River in the vicinity of Toledo, Ohio, near Lake Erie, and one area (3) on the River Raisin at Monroe, Michigan, were sampled (Figure A2).

3. Area 1. Area 1, known as Island 18, was in Maumee Bay northeast of Toledo and was approximately 160 acres in size. The area was soft and rather poorly designed for surface drainage, with only one weir in the northeast corner. At the time the area was sampled (May 1975), nearly one half was covered with scattered pockets of surface water having depths up to 4 ft. Five sample sites were selected for data collection, and a photograph was taken to depict the area for comparison with other areas (Plate A1). Cone index data collected at each site (Table A1) and all soils data are summarized in Table A2. Little or no surface crust was apparent in the fat clay (CH) soil in the area.

4. Area 2. Area 2 was on the Maumee River near Riverside Park, Ohio, and encompassed approximately 30 acres. The area was relatively firm silty clay (MH), was uniform in strength as indicated in Table A1, and had no evident surface crust. Plate A2 indicates the location of five data sites selected in the area.

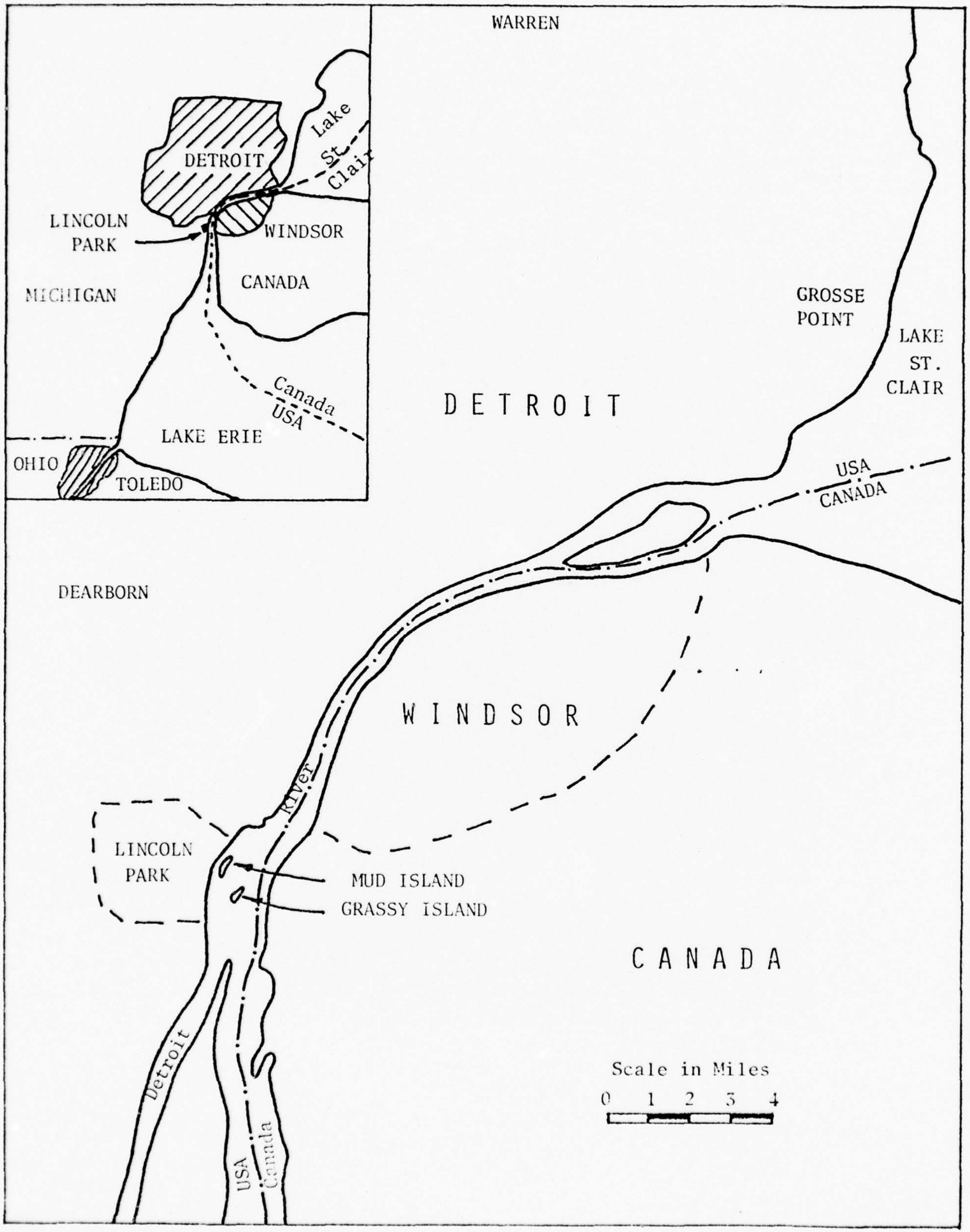


Figure A1. Location of unsampled containment areas near Lincoln Park, Michigan

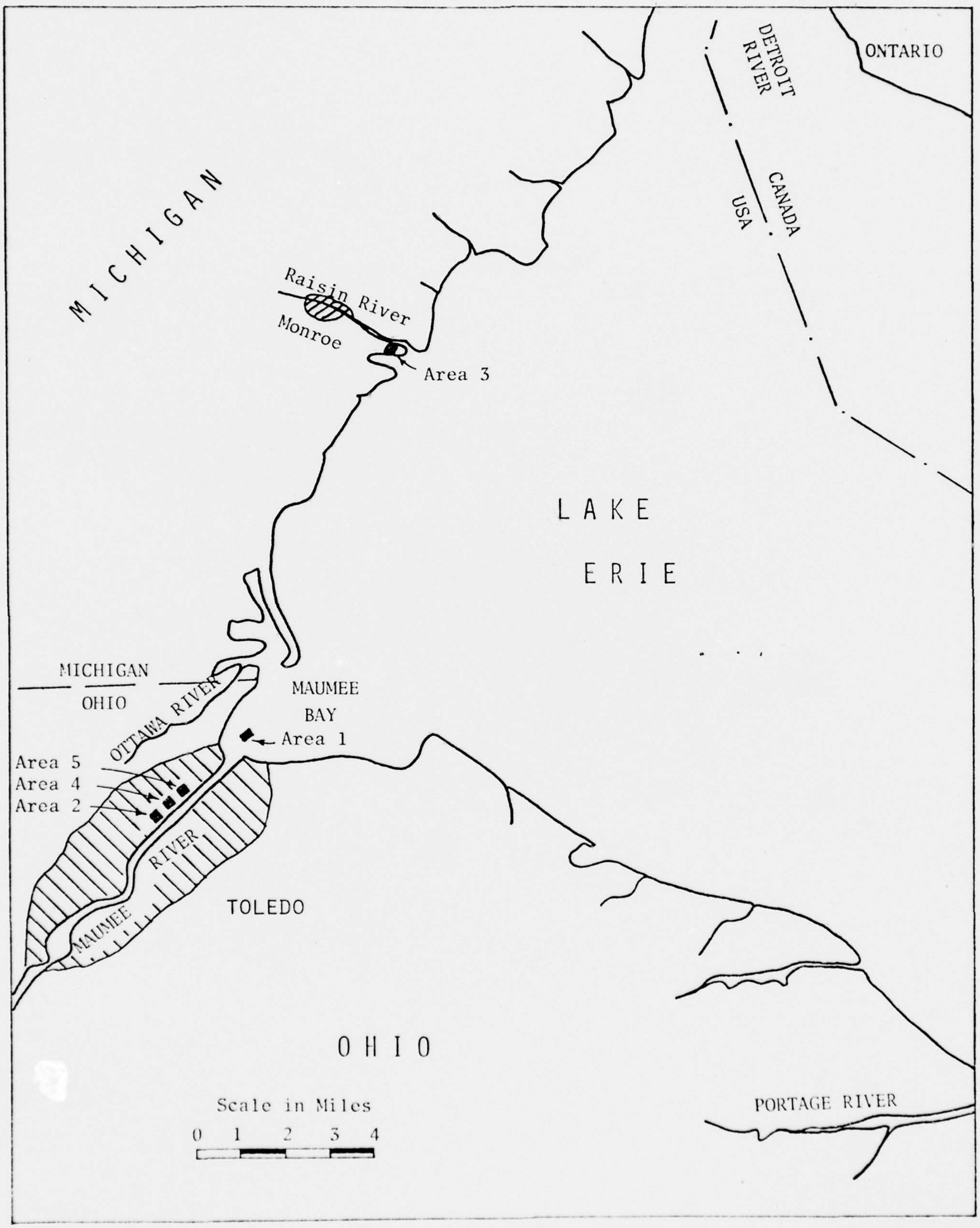


Figure A2. Locations of containment areas in Detroit District near Toledo, Ohio

5. Area 3. Area 3, on the Raisin River, was northeast of Toledo in Monroe, Michigan. The site was actually a low marshy area of Lake Erie that had been partially diked on three sides, with surface water allowed to drain into Plum Creek and eventually back into Lake Erie. The soil was ailty clay (MH) with little or no crust and varied in strength relative to the four sampling locations selected in the area (Plate A3).

6. Area 4. Area 4 was located northeast of area 2 on the Maumee River and was known locally as Penn 8. The area encompassed was approximately 32 acres with fat clay (CH), silty clay (MH), and silty sand (SM) soil types. Five sites were sampled (Plate A4). Sites 1 and 2 were located near the weirs and were relatively soft (Table A2), and the other sites, 3-5, were relatively firm with little or no surface water.

7. Area 5. Northeast of areas 2 and 4, but still on the Maumee River, area 5 (Penn 7) was recently used as a disposal site (1975) and some surface water remained along the northeast dike (Plate A5). The 30-acre area was composed of fat clay (CH) soil and was relatively soft and uncrusted so that only three sample sites could be established.

Chicago District areas

8. Three dredged material containment areas in southeastern Chicago near the southern shore of Lake Michigan (Figure A3) were visited and sampled in May 1975.

9. Area 1. Area 1, known as Stoney Island, had been used frequently for disposal of material dredged from the Calumet River. The total area inclosed by dikes was approximately 40 acres. The area was poorly drained and at the time it was sampled, 20 percent of it was covered with surface water (Plate A6). Six sample sites were established in an area of silt (ML), where there was no surface water or surface crust (Table A1).

10. Area 2. Area 2, approximately 100 acres in size, was south of area 1, adjacent to the Thomas J. O'Brien Lock and Dam on the Calumet River. Vegetation had sprung up throughout the area and no surface water present (Plate A7). Four sites were established, two in silty

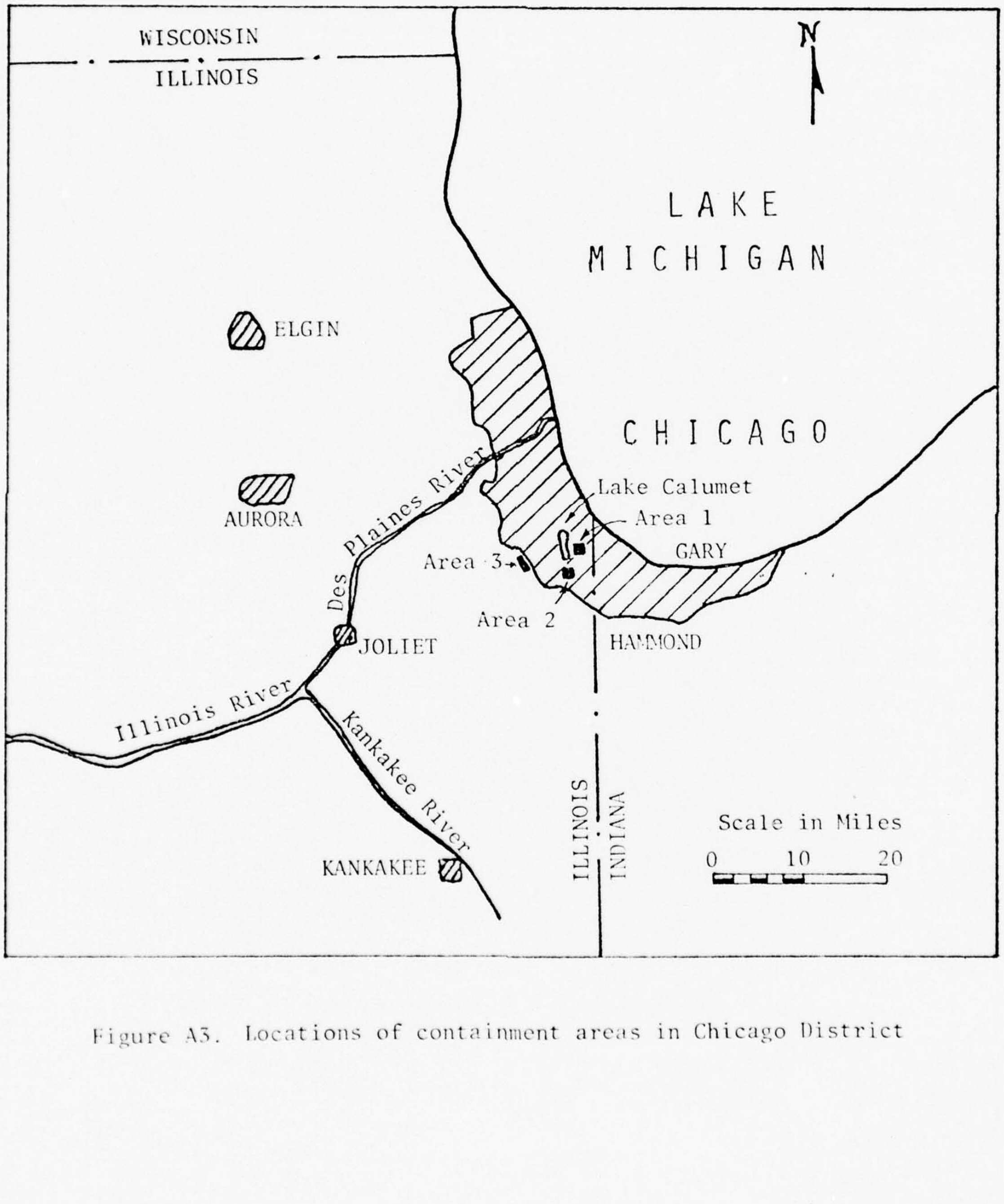


Figure A3. Locations of containment areas in Chicago District

clay (MH) and two in sandy silt (SM) with no apparent surface crust at any site (Table A1).

11. Area 3. Area 3, west of areas 1 and 2 and parallel to the Calumet Sag Channel and Interstate 294, an elongated disposal area of approximately 30 acres, was last used in 1973 for disposal of material dredged from a portion of the channel 10 miles away. The area had been divided in the middle by a dike to permit comparison drainage by standard weirs on the east end and siphon or pipe weirs on the west. At the time of sampling, the siphons were plugged, and the weirs were too high in the dike to permit drainage. Consequently, water had ponded along the southern dike in both ends of the area (Plate A8). Six sample sites, three in each end, were established in silty clay (MH) soil. Data from the sites (Table A1) indicated nonuniform cone index measurements; there was no apparent crust. The softer material, of course, was nearest the ponded water.

New Orleans District areas

12. Three dredged material containment areas in the vicinity of New Orleans were visited and sampled. Areas 1 and 2 (Figure A4) were typical of disposal sites along the lower Mississippi River, and area 3 was typical of disposal sites along shipping lanes serving areas adjacent to New Orleans.

13. In addition, seven dredged material containment areas (4-10) were selected for sampling in the Lake Charles-Lake Calcasieu area as being representative of dredging and disposal operations in that part of the New Orleans District. The maintenance dredging of the Calcasieu River Channel was in full operation during data collection (October 1975), and only four of the seven areas were accessible for sampling.

14. Area 1. This dredged material disposal area was southeast of New Orleans and along the Southwest Pass of the Mississippi River. The area, 2.5 miles below the navigation point known as Head of Passes, lay along the northern edge of Southwest Pass adjacent to Riverside Bay at Navigation Light 27. The area was undiked with indefinite boundaries due to the instability of the underlying material, which prevented building dikes or levees in the marsh around the disposal area (Plate A9).

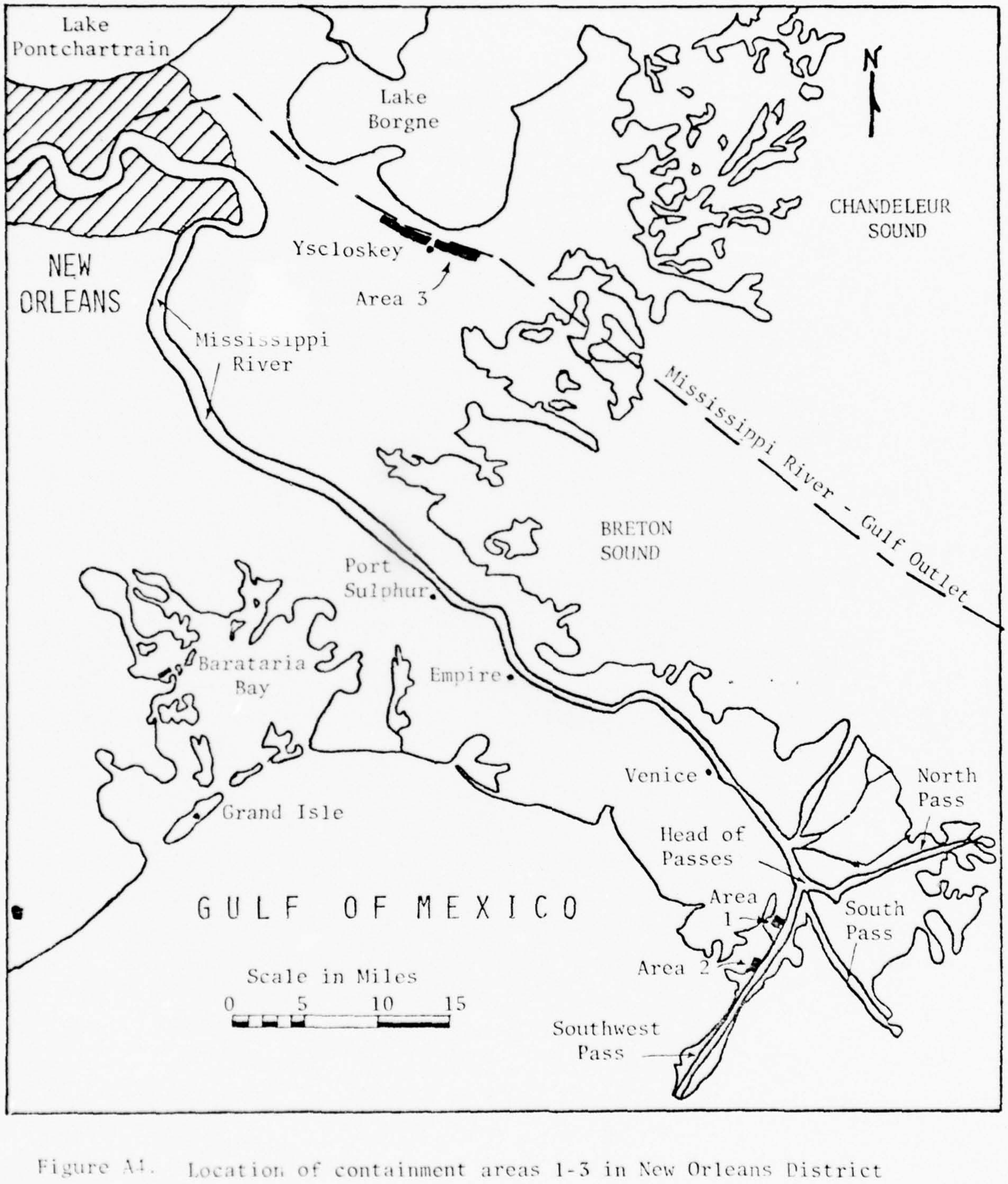


Figure A1. Location of containment areas 1-3 in New Orleans District

Instead, generally bowl-shaped marshy areas had been selected and pumped full of material (usually sand (SP)) to the general level of the surrounding terrain. One sample site was selected near the middle of the area.

15. Area 2. Located 2.5 miles farther downstream from area 1, area 2 was adjacent to Dixon Bay on the north side of Southwest Pass (Plate A10). Soil conditions at the only site sampled, near the middle of the area, were essentially the same as those of area 1, and the soil strength was essentially the same (Table A2).

16. Area 3. This dredged material containment area was adjacent to the Mississippi River-Gulf Outlet, which was dredged to provide a shorter (than via the Mississippi River) outlet to the Gulf of Mexico from eastern New Orleans. The sample site for the area was near the south shore of Lake Borgne (Figure A5) and was selected because of its ease of accessibility. The site was in the middle of the 0.75-mile-wide disposal area adjacent to the outlet (Plate A11). The entire disposal area was thickly vegetated, and the soil was rather firm silt (ML) (Table A2). No surface water was present at the time of sampling (June 1975).

17. Area 4. Southwest of Lake Charles, Louisiana, this 310-acre area was last used for disposal in 1973. Silty sand (SM) and fat clay (CH) dredged from the Calcasieu River (Figure A5) had been deposited into the area. The soil was rather firm when sampled (Table A2), and the surface was completely covered with heavy cane and marsh grasses (Plate A12). No surface water was present.

18. Area 5. This 310-acre area southwest of area 4 had not been used in recent years, but was being prepared (dikes raised) for pumping in 1976. Most of the soil in the area was crusted fat clay (CH), with a small central portion of the area composed of silty sand (SM). The clay was still rather soft below the surface, as shown by the cone index data in Table A1, but the sandy area was firm with no vegetation. No surface water was present in the area (Plate A13).

19. Areas 6, 7, and 8. These three areas were northeast of areas 1 and 2 along the Calcasieu River and had recently been filled or were

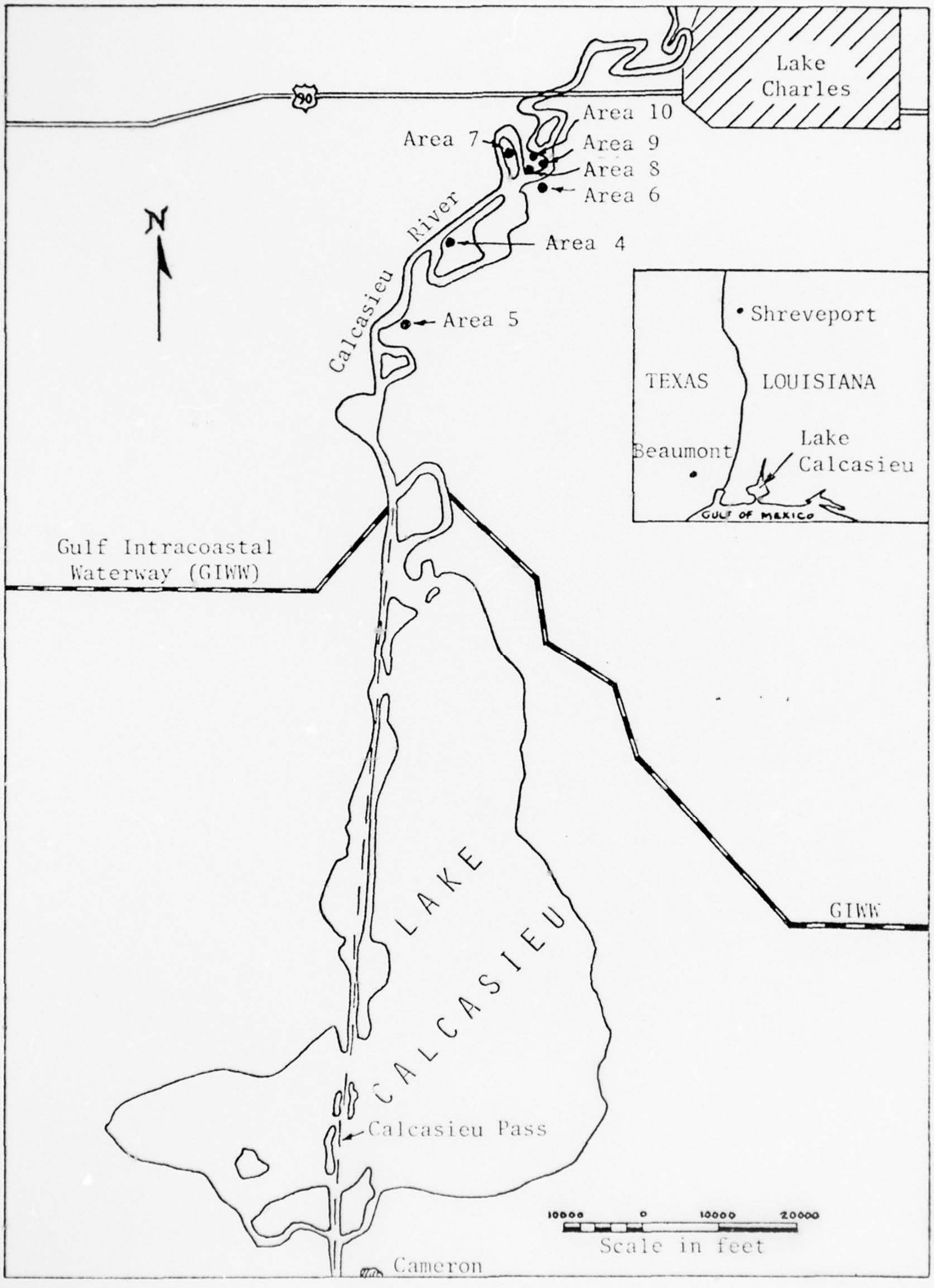


Figure A5. Location of containment areas 4-10 in New Orleans District

being filled with dredged material during data collection. The areas were covered with a fluid mixture of water and soil that prevented sampling. Area 6 (Plate A14) was the largest with 425 acres; area 7 (Plate A15) had 125 acres; and area 8 (Plate A16) was much smaller with 70 acres.

20. Area 9. Located nearly adjacent to area 8, area 9 was a nonhomogeneous area of silty sand (SM) with three distinct soil conditions, as shown by the soils data in Table A2. Data collection sites were established in areas representative of each of the conditions (Plate A17). Some surface water was present in the softer areas, but little or no vegetation was present.

21. Area 10. This small silty sand (SM) area of about 30 acres was adjacent to area 9 on the north. The soil was firm (Table A2), and the entire area was covered with vegetation (Plate A18). Only one sample site was selected because of the relative homogeneity of the conditions in the area.

Seattle District areas

22. Six dredged material containment areas were visited in the Seattle District during September 1975 (Figure A6). Areas 1 through 4 were north of Seattle along Puget Sound, and areas 5 and 6 were southwest of Seattle along Grays Harbor. The areas were typical of those used for dredged material disposal operations in the northwestern United States.

23. Area 1. Area 1 was some 50 miles north of Seattle near Anacortes, Washington, and was an 18-acre future industrial site. Dredging operations had begun only 8 days before the visit, and very little material was visible within the diked area. In the pumping operation, a cutterhead dredge with 24-in. disposal pipe was dredging material from the nearby Anacortes Navigation Channel and depositing it into the confined area. The facility, to be developed as an industrial site by the city of Anacortes, was to be filled with 600,000 yd^3 of material in a 10-week period under a CE maintenance dredging contract, then turned over to the city for development. No soils data were collected, but a photo and sketch of the area are shown in Plate A19.

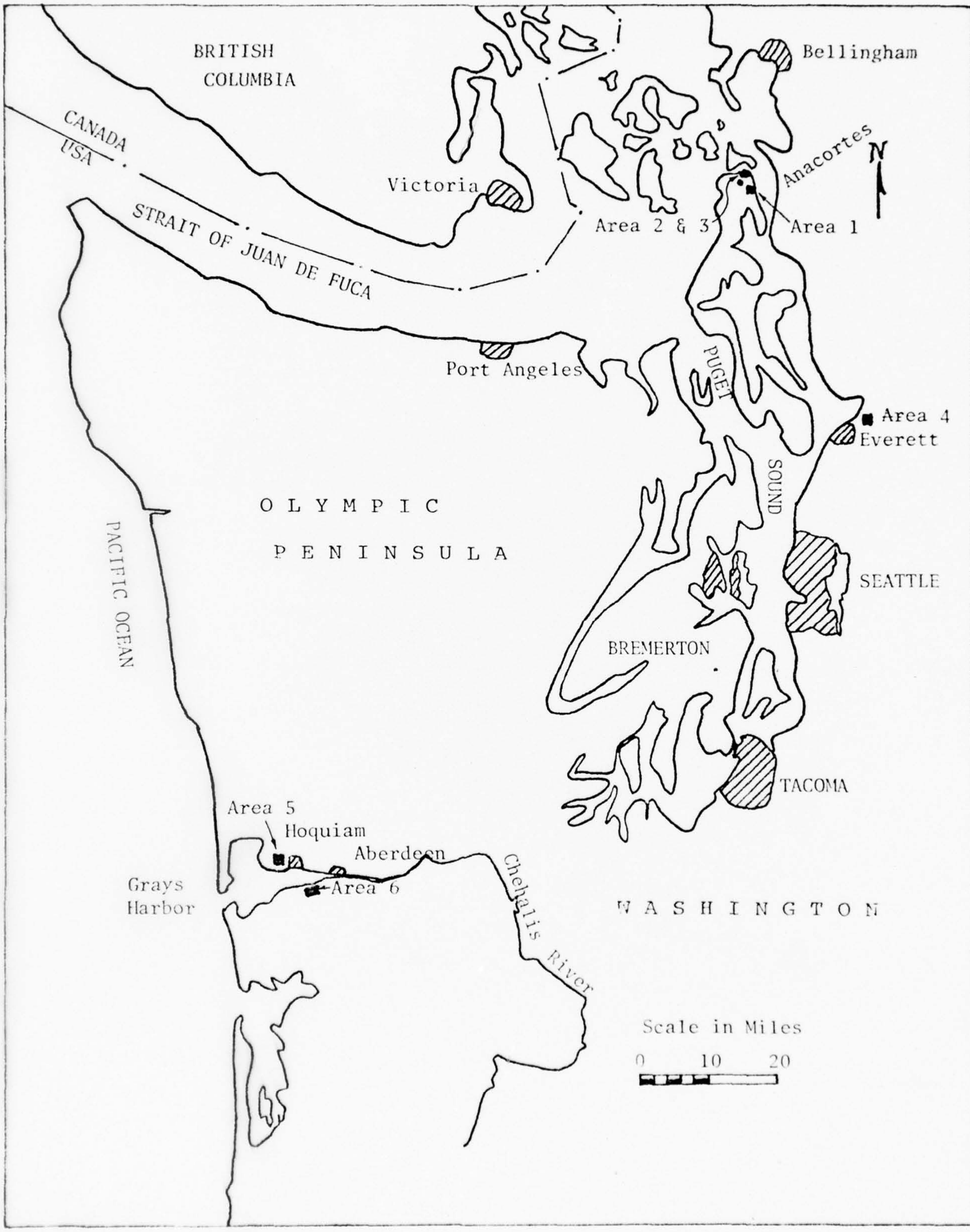


Figure A6. Location of containment areas in Seattle District

24. Areas 2 and 3. Areas 2 and 3 (Figure A6) were developed simultaneously through stages disposal operations as a portion of the Capsante Waterway Project adjacent to the Anacortes Navigation Channel. Approximately 60,000 yd^3 of organic silt (OL) were dredged from Capsante and deposited into area 2; the finer material in suspension flowed by pipe into area 3 for settlement. As shown in Table A2, the average cone indexes of the two areas were about equal (10 and 12); and both areas had some surface crust. Some surface water was present along the dikes, as shown in Plates A20 and A21.

25. Area 4. Area 4, northeast of Everett, Washington, was composed of fine sand (SP) pumped in 1973 from the nearby Snohomish River. The area was relatively dry and firm with sparse vegetation. No surface water was present (Plate A22). The entire area had been leased to a local paving contractor for the material.

26. Area 5. Some 100 miles southwest of Seattle along Grays Harbor (Figure A7), this 88-acre area was created with dredged material from the Chehalis River channel at Hoquiam. About 375,000 yd^3 of fine sand (SP) and silt (ML) were deposited into a 70-acre diked area, with the finer material carried in suspension and allowed to settle in an 18-acre tract to the northwest. The entire area had crusted over, as shown by the cone index data in Table A1, although some soft areas were still present as shown by the data for site 3. Some surface water was present along the dikes, and some vegetated areas (mostly small willows) were present inside the 70-acre area (Plate A23). The sandy material, nearest the Chehalis River, had been purchased and was being removed by a paving contractor during WES data collection.

27. Area 6. Area 6, a 100-acre site on the opposite bank of the Chehalis River channel, had been filled with 250,000 yd^3 of silty (MH) in July 1975. The area was soft and relatively wet, as shown in Table A2, with surface water in the southern hald of the area (Plate A24). Annual disposal operations are scheduled for the next 3 or 4 yr in this area before the CE releases it to Weyhauser Lumber Company as a pulpwood retention basin or log storage area.

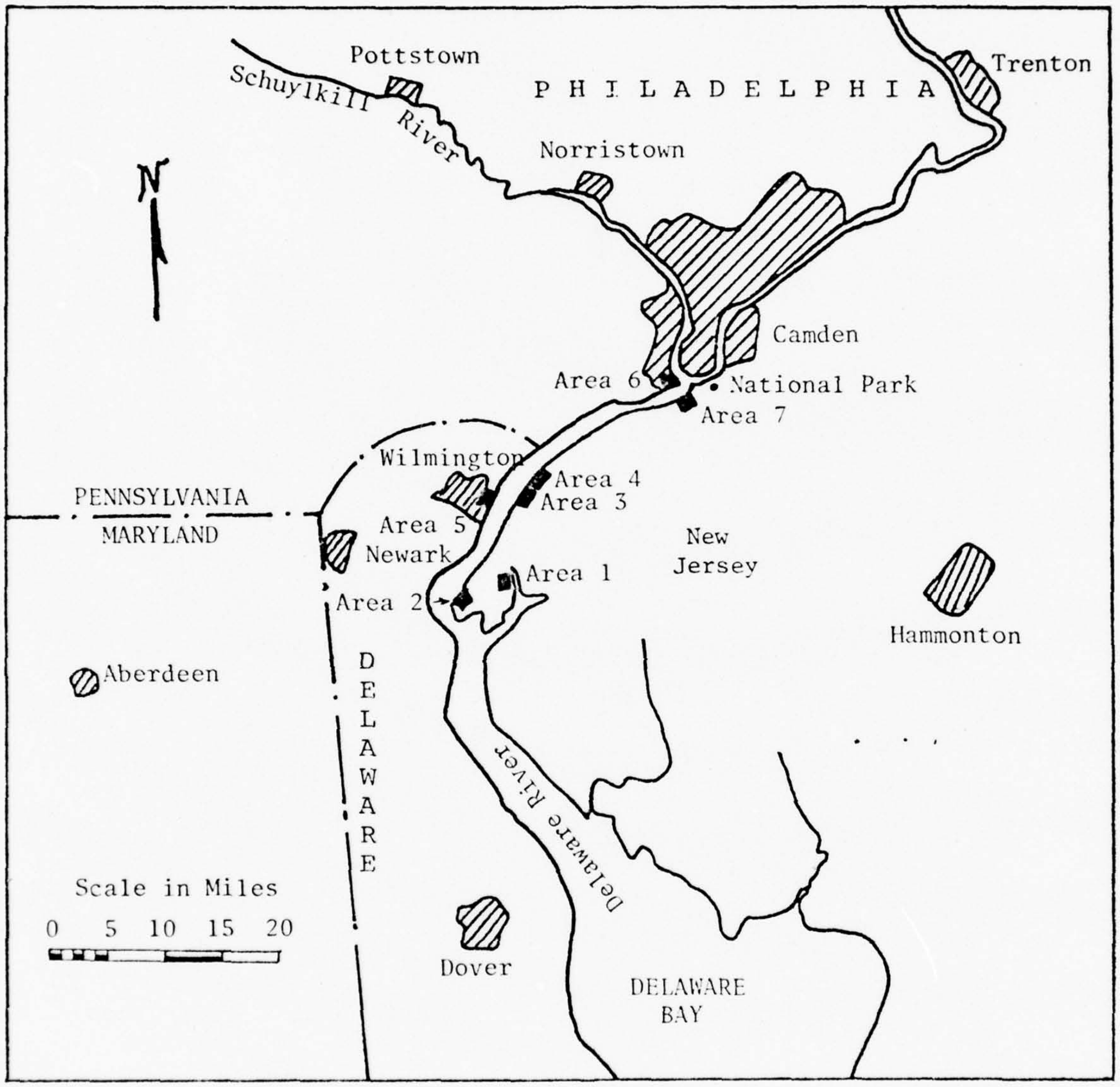


Figure A7. Locations of containment areas in Philadelphia District

Philadelphia District areas

28. Seven dredged material containment areas (Figure A7) were sampled in the Philadelphia District in September 1975. The areas are used periodically by the Philadelphia District to dispose of material dredged from the Delaware, Schuylkill, and Christina rivers to maintain navigation channels in these rivers. The areas selected were typical of the 7500 acres of disposal facilities now under lease to the Philadelphia District.

29. Area 1. Area 1 was 397 acres of silty clay (MH) and silty (ML), located southeast of Wilmington, Delaware, in an area of New Jersey known as Penn's Neck. Sites 1 and 2 (Plate A25) were located near the sluice gates and were relatively soft (Table A2), while site 3 was located near the discharge pipe and was very hard. The only surface water present from 1974 disposal was ponded in the south corner of the area. Heavy growths of phragmites (reeds and cane) covered the northern and eastern portions of the area.

30. Area 2. This 1430-acre area southwest of area 1 was near Fort Mott, New Jersey, in an area referred to locally as Killcohook. The area was completely covered with 6- to 8-ft phragmites (Plate A26) and was relatively firm, as shown in Table A2. Sites 1 and 2 near the sluice gates were the softest, but were in the finer silty clay (MH), compared to the silt (ML) in the northern part of the area (sites 3 and 4). No surface water was present during data collection (September 1975), although the area had been used for disposal 1 yr earlier.

31. Area 3. This 570-acre area, known locally as Pedricktown South, was northeast of areas 1 and 2 near Pedricktown, New Jersey. The area had been used previously and was completely covered with vegetation. At the time of sampling (September 1975), the area was again being filled with dredged material (Plate A27). Only two data collection sites were established in the area because of the presence of newly pumped material that was too soft to sample. Site 1 was nearer the new material than site 2 (Table A2), and both were in silty clay (MH) material.

32. Area 4. This 700-acre area northeast of area 3, known locally as Pedricktown North, had been used previously and during data collection (September 1975) was being used as a borrow area for silt (ML). Some surface water and vegetation were present (Plate A28) at the only site that could be established in the area.

33. Area 5. Area 5 was southeast of Wilmington, Delaware, on the southern end of Cherry Island. This was a 231-acre, two-celled area (Plate A29) used for disposal of silty clay (MH) dredged from the navigation channel of the Christina River. The area had been pumped recently (September 1974), but was relatively firm during data collection (September 1975), as shown by the cone index data in Table A1, except for some softer material present below 9 in. at site 1. Heavy growths of grass were present in the area.

34. Area 6. This containment area, southwest of Philadelphia at Fort Mifflin, Pennsylvania, had included 139 acres, but in 1975 the containment area was being increased in size by the diking of an additional 180 acres for disposal use. The 139-acre area sampled in September 1975 had been pumped the previous year in maintenance dredging of the Delaware and Schuylkill Rivers. Four data sites were established in the 139-acre area (Plate A30): sites 1 and 3 in a soft silty clay (MH) and sites 2 and 4 in a rather firm silty sand (SM). There was some surface water and nearly 100 percent coverage of the area with assorted species of vegetation.

35. Area 7. The National Park Disposal Area (area 7), 154 acres, was near National Park, New Jersey, across the Delaware River from Philadelphia. Three data sites were established (Plate A31): sites 1 and 3 in a rather firm silty clay (MH) and site 2 in a firm silty sand (SM). Thick vegetation, but little or no surface water, was present.

Galveston District areas

36. Three containment areas (1-3) were selected around Port Arthur, Texas, for data collection. The areas were generally representative of the range of soil types and strengths occurring in that area. Five areas (4-8) were selected near Houston, Texas, as representative dredged

material containment areas in that part of the Galveston District. The areas were near the Houston Ship Channel, from which the dredged material was pumped. Three areas (9-11) were selected in the vicinity of Galveston for data collection (in October 1975). The containment facilities were rather large, but had been filled recently and were still relatively soft. One area (12) was visited and sampled in the Freeport area, and two (13 and 14) in the vicinity of Corpus Christi, Texas.

37. Area 1. Area 1 was 450 acres of fat clay (CH) northeast of Port Arthur at the junction of the Neches River and Sabine Lake (Figure A8). The area had been recently used for disposal and was crusted and relatively soft at sample sties (Table A2). Site 1 was covered with surface water (Plate A32). Material for the fill in the area had been dredged from a harbor and dock area nearby in the Sabine-Neches Canal, which is a portion of the Gulf Intracoastal Waterway.

38. Area 2. This was a 510-acre area of firm fat clay (CH) southwest of Port Arthur adjacent to the Intracoastal Waterway (Figure A8). Fill for the area had been dredged from the Port Arthur Harbor east of the area. The entire area was crusted, dry, and uniform, had no surface water, and was completely covered with vegetation (Plate A33). Cone index and soils data for the only sample site selected because of the area uniformity of soil conditions in the area are shown in Tables A1 and A2, respectively.

39. Area 3. South of Port Arthur and southeast of area 2 (Figure A8), this 395-acre area was crusted, dry, and uniform in soil strength. Material for the area had been dredged from the adjacent Port Arthur Canal along Sabine Lake. Three sample sites were established in the area of fat clay (CH) (Table A2). No surface water and very little vegetation was present (Plate A34).

40. Areas 4 and 5. These two interconnected areas, known as West Jones North and South Cells, were north of Pasadena, Texas, and east of Galena Park, both east of Houston (Figure A9). North Cell (area 4) was 85 acres in area and South Cell (area 5) was 90 acres, with an earthen levee between and a weir-culvert controlling flow between the areas of

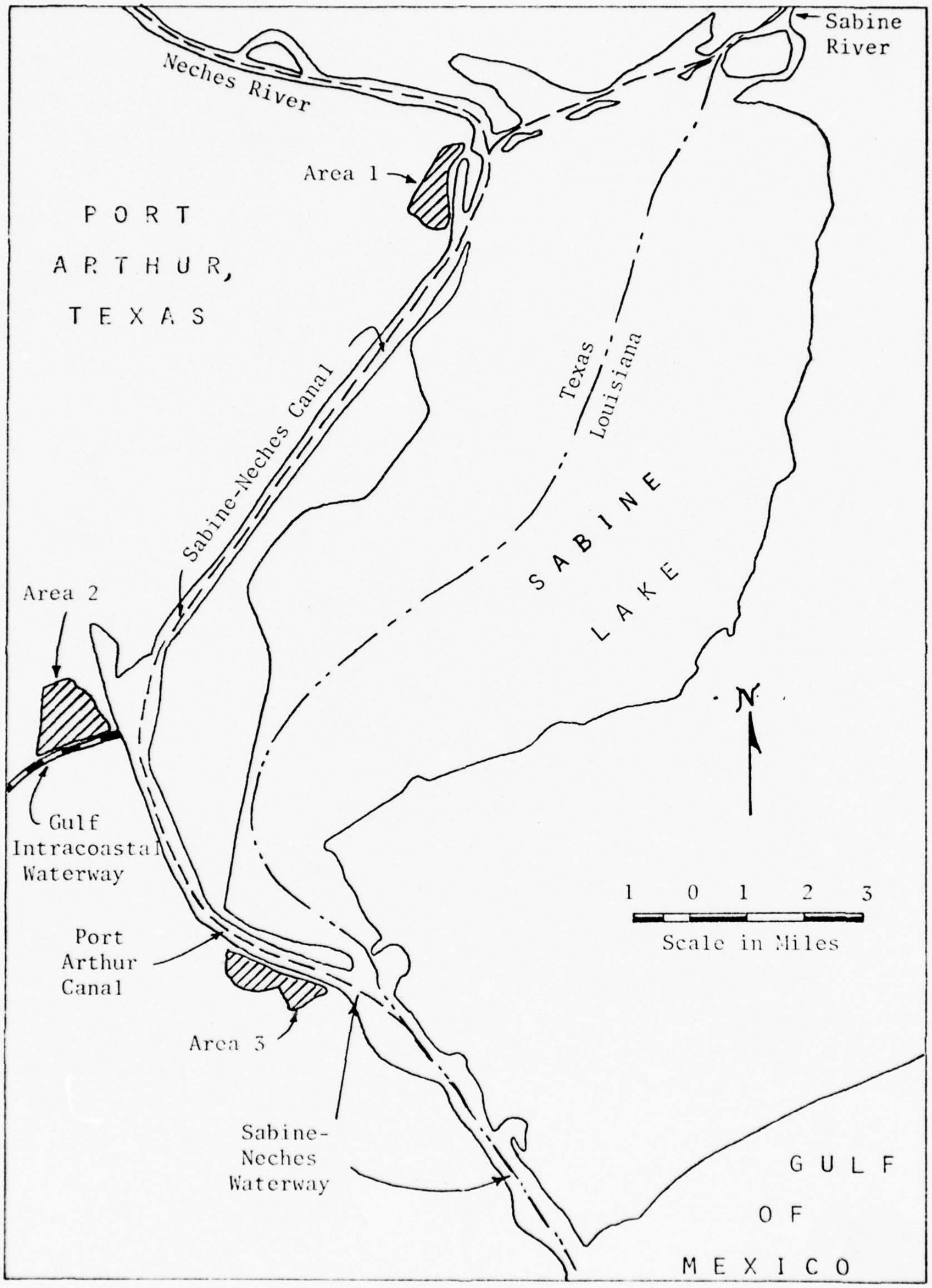


Figure A8. Location of containment areas 1, 2, and 3 in Galveston District

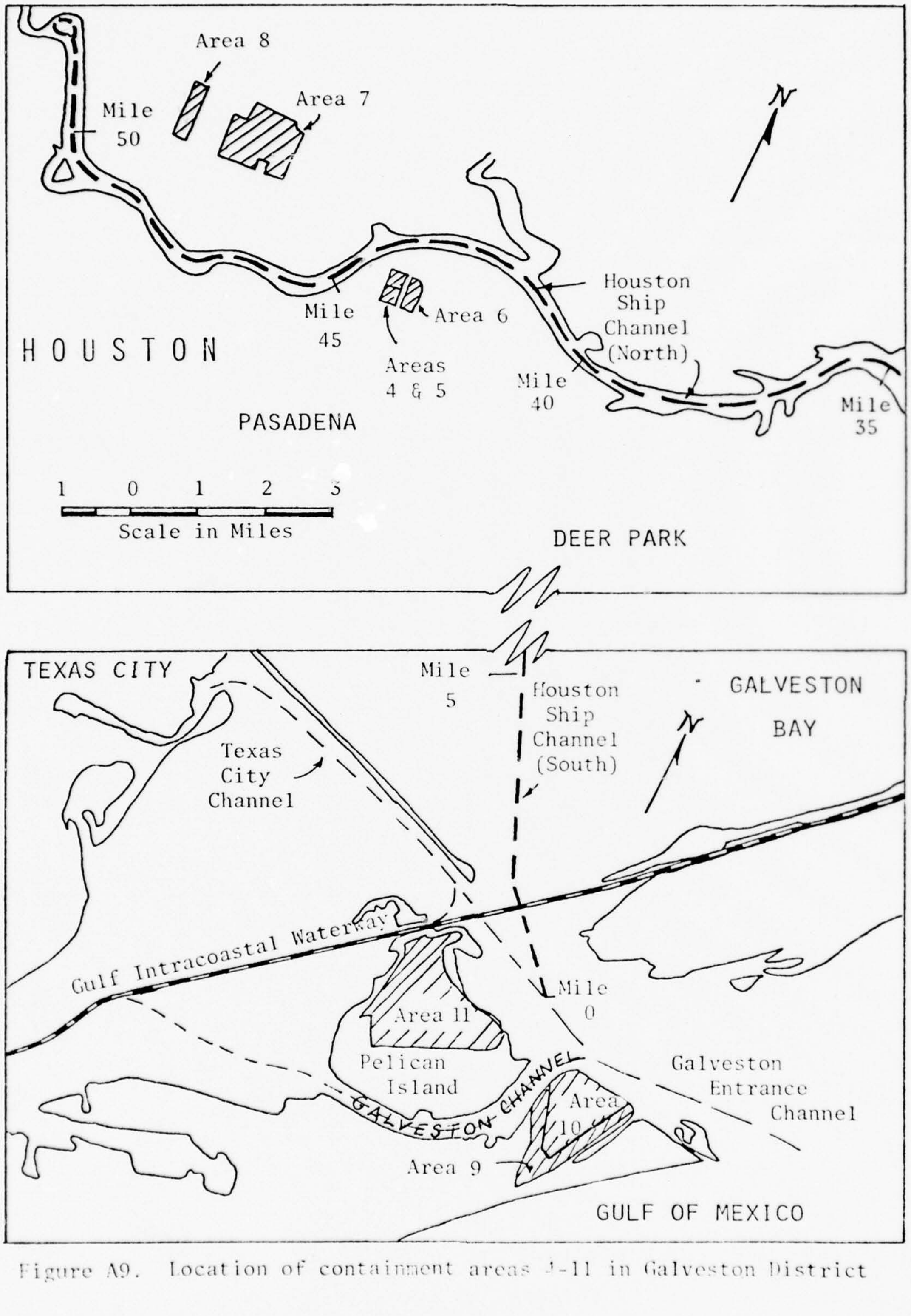


Figure A9. Location of containment areas 4-11 in Galveston District

lean clay (CL) soil. Both areas had been filled recently; the material was pumped into the North Cell (Plate A35) and allowed to flow through the weir-culvert into South Cell (Plate A36). Both areas were very soft. The material to the 36-in. depth in South Cell was slightly softer and finer in texture than that in North Cell by virtue of the filling technique.

41. Area 6. Across a road from West Jones (areas 4 and 5, Figure A9), East Jones (area 6) was a 105-acre area of crusted, but soft, lean clay (CL). The material had been pumped into the north end of the area, and water had eventually ponded at the south end (Plate A37). Two data collection sites were established in the north end of the area. Soils data for the sites, shown in Table A2, indicate a rather uniform area relative to soil strength. The area was overgrown with patchy marsh grasses and cattails.

42. Area 7. This 580-acre area, called the Clinton Disposal Area, was north of Galena Park, Texas (Figure A9), and was being filled during data collection (October 1975). The area was bisected by a secondary road atop a raised levee under which numerous culverts had been placed connecting the two sections (Plate A38). Most of the area was covered with liquid lean clay (CL) material except for the southwest corner, where a single data collection site was established. As shown by the cone index value (Table A1), this portion of the area was slightly crusted, but still very soft.

43. Area 8. A smaller 70-acre area west of the Clinton area, known as the Glendale Disposal Area, was visited but was not sampled because of the fluid material still remaining from a recent disposal operation. As shown in Plate A39, the area was completely covered with surface water.

44. Areas 9 and 10. This dual-celled 875-acre area, northeast of the city of Galveston in the Fort San Jacinto area, was near the intersection of the Houston and Galveston ship channels and adjacent to the Gulf of Mexico. As shown in Plates A40 and A41, the larger cell, area 10, was partially surrounded by area 9. The two areas were interconnected to it by culverts and weirs. Dredged material had been

pumped into area 10 and allowed to flow out of the weirs and culverts into area 9. Consequently, as shown in Table A2, area 9 was much softer than area 10. The soil in both areas was fat clay (CH). Some vegetation had grown in the areas before the last filling, and some of the taller of the grasses and canes were protruding through the muck in the two areas.

45. Area 11. Area 11 was at the junction of the Houston and Galveston ship channels and adjacent to the Texas City Ship Channel. This large (1590-acre) disposal area was known locally as Pelican Island and was just north of the city of Galveston in Galveston Bay. The area had just recently been filled with material dredged from the Galveston Ship Channel. The fat clay (CH) was still very soft, except in the southeast corner, where the surface was not inundated by water. Two sample sites were selected (Plate A42) for data collection. No vegetation was visible in the area.

46. Area 12. Area 12 was 150 acres of fat clay (CH) south of the city of Freeport and parallel to the Gulf Intracoastal Waterway (Figure A10). The area had been filled in 1974 and was still very soft during data collection (October 1975). A cross dike had been constructed out into the area near the west end to channel flow toward the outflow weir nearby, but water had ponded between the cross-dike and the dike on the southwest (Plate A43). Sparse vegetation had grown near several inflow sites on the northwest side of the area.

47. Area 13. This 295-acre area north of Corpus Christi (Figure A11) was at the junction where the Corpus Christi Ship Channel enters Corpus Christi Bay. The area is used to hold polluted material dredged from the Corpus Christi Channel, which contains extremely fine fat clay (CH) material, and when placed in suspension requires an extended period of containment prior to settlement. The water is allowed to evaporate rather than run off because of the pollution problems and the slow settlement rate of the suspended solids. The area was crusted and rather soft (Table A2), with some water ponded on the west side, as shown in Plate A44.

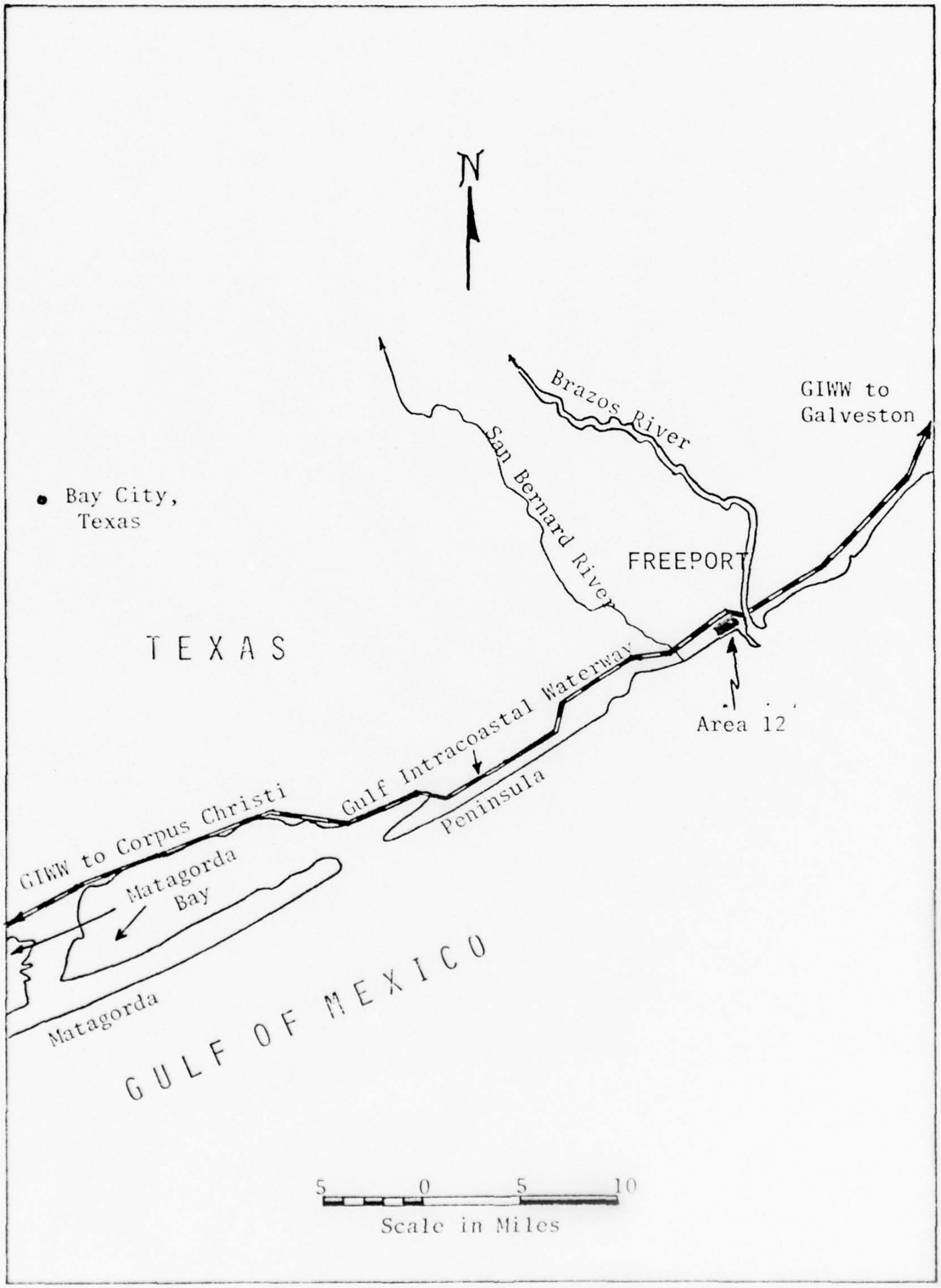


Figure A10. Location of containment area 12 in Galveston District

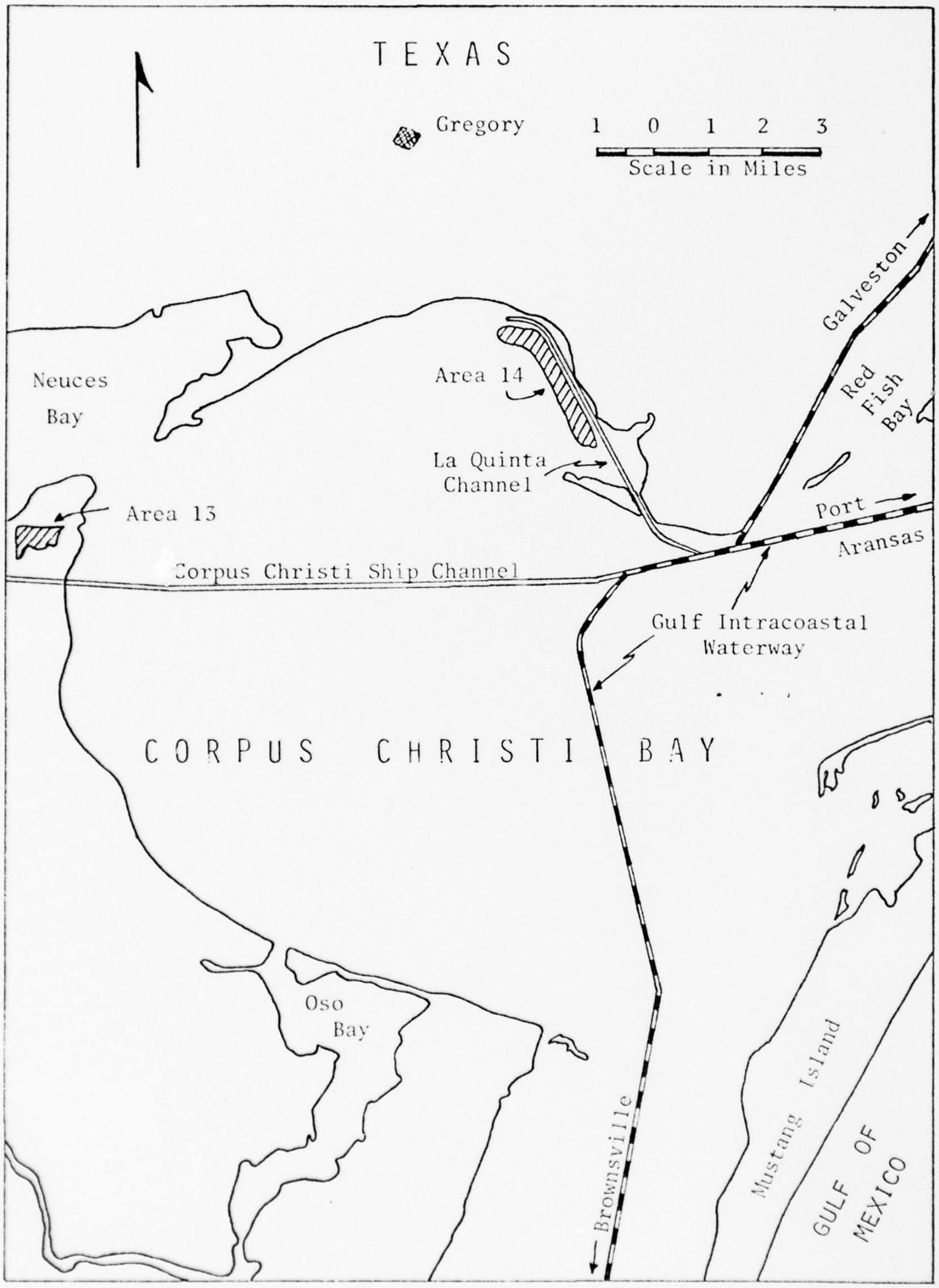


Figure A11. Locations of containment areas 13 & 14 in Galveston District

48. Area 14. This 100-acre artificial island in Corpus Christi Bay near Ingleside, Texas, was being created from material dredged from the La Qunita Ship Channel. The dredge was building the perimeter walls during the WES data collection, and the area was visited only by boat. No soils data were collected, but a photo of the area is shown in Plate A45.

Mobile District areas (resampled)

49. To establish representative soil data for comparison with other dredged material containment areas in this study, the two dredged disposal areas on Blakeley Island, Alabama, which were originally sampled in April 1974[1], were resampled in June 1975.

50. Area 1. Located on the north end of Blakeley Island adjacent to the Mobile River (Figure A12), this 85-acre area of generally fat clay (CH) was relatively soft at the time of sampling. About 20 percent of the area was covered with surface water (Plate A46). Four sample sites were selected in the area not covered with water, and soil data were collected at each site as shown in this appendix. Some crust was evident in readings for all of the sites except site 3.

51. Area 2. Located on the south end of Blakeley Island (Figure A12), area 2 was 175 acres of fat clay (CH) slightly firmer than the soil of area 1 (Table A1). Some surface water was present, as shown in Plate A47, and some surface crust had formed in the area.

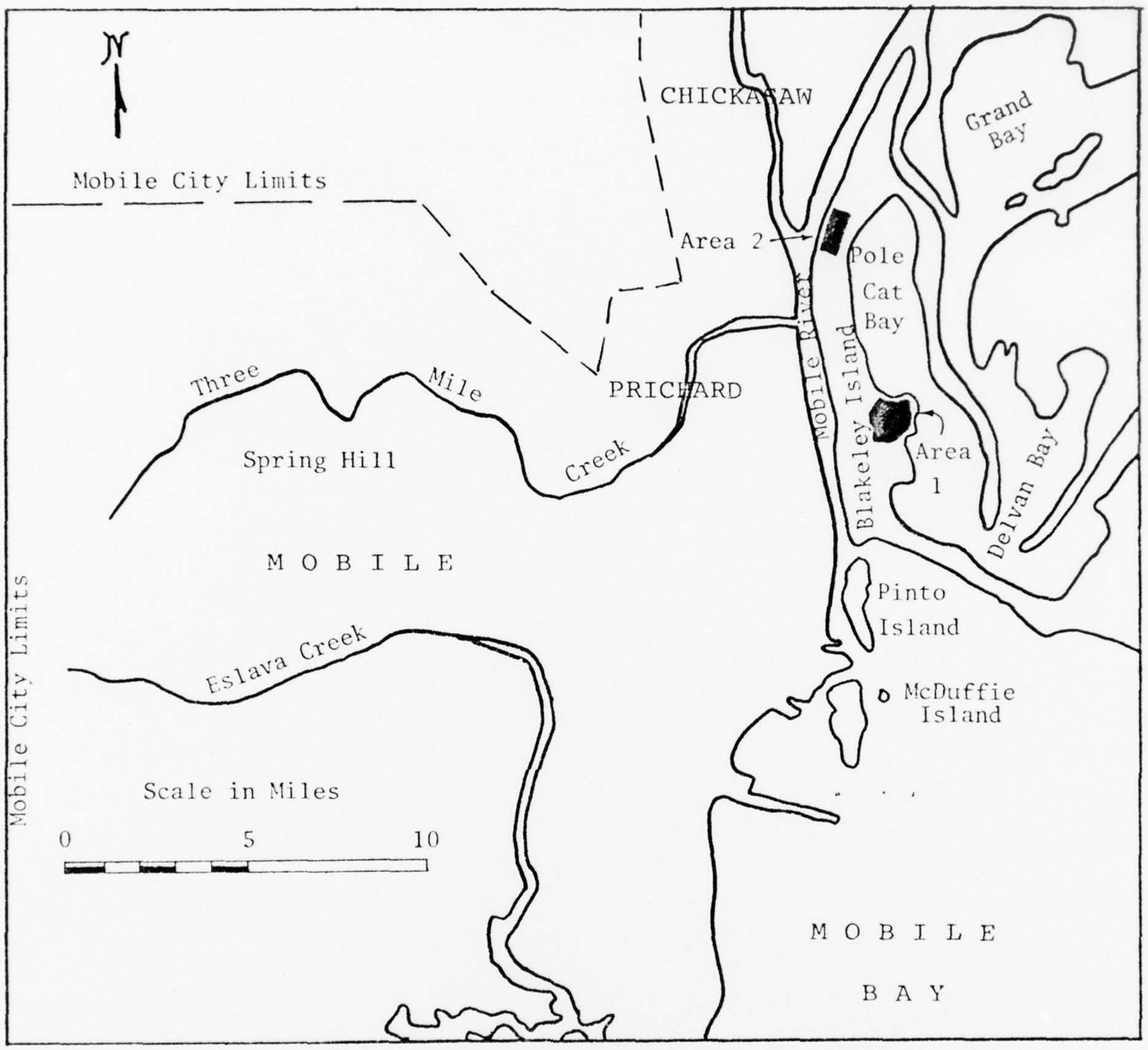


Figure A12. Location of containment areas in Mobile District

Table A1

Basic Cone Index Data

Area No.	Site No.	0	1	2	3	4	5	6	9	12	15	18	24	30	36
		Average Cone Index at Depths Indicated, in.													
		Detroit District													
1	1	1	4	2	0	0	0	0	0	1	1	2	3	2	3
	2	8	11	12	8	5	5	5	5	7	7	8	10	10	12
	3	14	17	16	9	8	5	5	4	6	6	8	19	46	64
	4	0	0	0	0	0	0	0	0	0	0	14	17	29	19
	5	12	7	4	4	4	4	4	3	5	6	9	15	24	35
2	1	24	56	78	82	78	83	84	84	84	82	84	97	98	122
	2	26	44	46	52	65	72	75	86	93	102	118	124	116	130
	3	28	49	51	50	51	54	55	76	96	94	126	132	118	238+
	4	28	44	61	70	68	81	87	93	93	99	100	111	124	140
	5	28	56	66	75	80	74	70	73	86	92	98	108	110	122
3	1	38	54	62	66	54	42	38	23	18	19	22	31	53	63
	2	48	58	61	48	42	37	36	32	27	38	47	52	57	61
	3	36	39	39	35	22	14	11	9	8	9	16	19	20	20
	4	4	6	8	7	5	4	4	4	4	6	8	11	13	13
4	1	11	15	18	20	25	31	34	37	41	51	46	45	47	60
	2	4	10	19	27	32	39	45	50	49	50	57	61	59	60
	3	16	35	50	47	52	54	58	54	58	60	64	78	90	102
	4	19	36	56	64	70	74	77	76	82	92	94	102	98	104
	5	22	46	66	67	69	68	72	76	82	84	83	94	108	111
5	1	0	3	10	18	32	44	44	50	66	111	186	300+	300+	300+
	2	0	2	4	8	13	18	20	26	32	37	47	58	67	94
	3	0	1	3	7	12	16	22	33	35	35	36	43	50	60
		Chicago District													
1	1	28	37	38	44	61	68	74	70	76	57	60	146	208	221
	2	24	36	48	62	65	68	74	81	68	68	59	63	96	127
	3	10	13	17	21	29	31	34	31	30	29	25	27	51	53
	4	12	15	26	43	55	65	73	69	70	69	71	76	91	100+
	5	12	18	27	37	52	66	74	82	92	86	76	135	177	214
	6	14	20	22	24	30	32	34	42	54	76	86	84	66	60
2	1	20	32	40	45	52	58	65	84	113	141	164	166	120	144
	2	32	58	80	96	108	117	132	152	115	120	92	97	68	70
	3	29	54	76	91	97	98	108	134	166	156	154	157	102	120
	4	22	35	41	46	50	62	78	56	32	23	26	30	33	37

(Continued)

Table A1 (Continued)

Area No.	Site No.	Average Cone Index at Depths Indicated, in. 0	1	2	3	4	5	6	9	12	15	18	24	30	36
		Chicago District (Continued)													
3	1	16	32	30	32	39	38	45	44	47	64	86	134	191	300+
	2	8	11	13	12	13	12	13	12	12	10	10	12	15	22
	3	36	52	48	48	51	56	54	54	46	42	38	44	44	44
	4	48	67	71	69	70	72	65	60	56	52	50	46	42	39
	5	14	15	16	16	18	21	21	19	14	12	12	12	14	16
	6	12	17	20	19	21	21	19	15	11	9	9	10	11	13
		New Orleans District													
1	1	41	100	155	209	280	352	403	467	363	289	263	299	387	537
2	1	34	84	147	213	284	357	427	512	582	592	594	623	606	617
3	1	32	67	96	126	144	147	160	163	184	184	148	129	115	116
4	1	50	99	137	152	158	178	192	161	86	106	146	**	-	-
	2	60	60	58	42	32	36	42	116	194	238	263	**	-	-
5	1	50	38	34	29	29	26	24	33	24	42	55	46	36	33
	2	78	103	170	244	336	425	444	546	507	253	223	110	97	100
6,7,8	1	*													
9	1	0	0	0	0	0	0	0	0	2	4	10	9	18	21
	2	16	17	14	17	27	28	25	20	11	12	12	16	20	20
	3	46	80	122	174	204	202	196	92	60	80	80	72	84	86
10	1	54	101	109	130	164	214	246	225	222	153	151	123	120	132
		Seattle District													
1	1	*													
2	1	11	16	13	9	7	7	6	6	7	8	10	15	19	21
	2	17	14	12	11	10	9	9	8	8	9	13	20	26	33
3	1	18	12	10	11	11	11	12	12	12	14	16	21	25	28
	2	16	14	14	13	12	11	11	12	13	14	18	**	-	-
4	1	7	20	52	104	176	266	350	563	676	750+	750+	750+	750+	750+

* No data. Dredged material being pumped into disposal area or area flooded.
** Bottom of fill area (not dredged material).

(Continued)

Table A1 (Continued)

Area No.	Site No.	Average Cone Index at Depths Indicated, in.													
		0	1	2	3	4	5	6	9	12	15	18	24	30	36
Seattle District (Continued)															
5	1	28	34	48	67	71	61	61	29	21	26	62	74	65	59
	2	54	68	59	38	35	34	36	38	54	59	78	184	275	287
	3	12	10	9	8	7	7	7	8	10	11	15	20	43	53
6	1	12	12	13	10	14	20	25	33	36	37	31	27	24	26
Philadelphia District															
1	1	42	26	22	13	8	5	4	4	5	5	6	8	14	19
	2	18	15	15	14	14	12	9	8	8	9	10	15	18	24
	3	472	343	262	217	182	178	165	113	147	133	123	130	180	178
2	1	50	50	52	51	44	48	39	47	86	72	75	73	78	85
	2	34	30	26	26	27	27	25	15	11	10	11	14	18	26
	3	110	134	138	108	118	149	190	236	188	212	166	110	106	104
	4	97	143	174	212	244	218	213	230	272	256	230	116	140	196
3	1	1	1	2	2	3	3	4	19	45	58	78	77	70	77
	2	28	34	36	38	36	45	54	62	62	62	72	59	60	67
4	1	26	40	41	36	40	39	56	192	348	434	372	438	370	376
5	1	56	60	58	52	48	48	44	48	59	76	70	68	42	41
	2	303	276	217	172	152	131	107	76	68	68	108	158	178	191
6	1	9	11	10	9	8	8	8	13	84	26	23	28	26	28
	2	50	124	330	400	393	384	436	750+	750+	750+	750+	750+	750+	750+
	3	4	4	5	6	7	8	8	203	189	750+	750+	750+	750+	750+
	4	21	59	98	130	161	180	198	244	290	392	529	629	750+	750+
7	1	35	40	47	50	52	52	59	66	68	67	54	41	33	32
	2	86	172	212	253	289	378	490	616	750+	750+	750+	750+	750+	750+
	3	42	116	222	224	278	274	274	322	344	382	492	636	690	750+
Galveston District															
1	1	*													
	2	20	11	9	7	7	7	7	24	26	27	24	33	25	25
	3	53	69	96	101	109	100	92	65	22	14	20	44	51	56
2	1	26	59	98	158	103	88	84	64	68	112	133	127	133	120

(Continued)

Table A1 (Concluded)

Area No.	Site No.	Average Cone Index at Depths Indicated, in. 0	1	2	3	4	5	6	9	12	15	18	24	30	36
		Galveston District (Continued)													
3	1	40	44	34	30	26	28	38	25	18	16	21	52	57	43
	2	53	47	37	28	24	20	18	15	14	35	48	27	35	56
	3	57	73	51	32	22	16	13	11	11	24	36	23	26	30
4	1	3	4	6	6	6	8	10	10	12	22	42	34	27	24
5	1	2	2	2	2	2	2	2	3	3	5	18	43	52	57
6	1	23	14	10	7	6	6	9	24	18	16	21	25	24	24
	2	24	21	17	13	11	10	9	33	30	29	30	37	33	35
7	1	*													
	2	9	11	11	6	7	8	8	9	10	10	8	8	9	10
8	1	*													
9	1	10	6	5	4	4	4	4	24	31	32	32	30	28	**
10	1	24	14	11	10	12	22	32	27	22	22	26	28	34	37
11	1	11	7	8	7	7	6	6	13	24	14	10	16	22	26
	2	44	25	19	21	29	61	92	110	22	22	98	34	21	52
12	1	15	12	11	8	7	6	6	6	6	7	8	11	17	19
	2	18	14	12	9	8	7	7	7	7	8	9	12	14	16
	3	9	7	7	6	5	5	4	4	4	5	5	9	12	15
13	1	40	29	27	25	22	19	16	15	30	44	38	39	47	43
14	1	*													
		Mobile District													
1	1	31	50	34	26	20	18	16	12	11	11	12	13	16	17
	2	19	14	11	12	12	10	9	8	6	6	6	7	8	10
	3	2	5	5	6	6	5	5	5	5	5	4	5	4	5
	4	17	17	12	10	8	7	6	5	5	6	6	7	8	10
2	1	50	27	13	7	6	5	5	5	5	5	6	8	10	14
	2	34	46	28	19	15	12	11	10	9	10	14	43	80	100+

Table A2

Summary of Soil Data

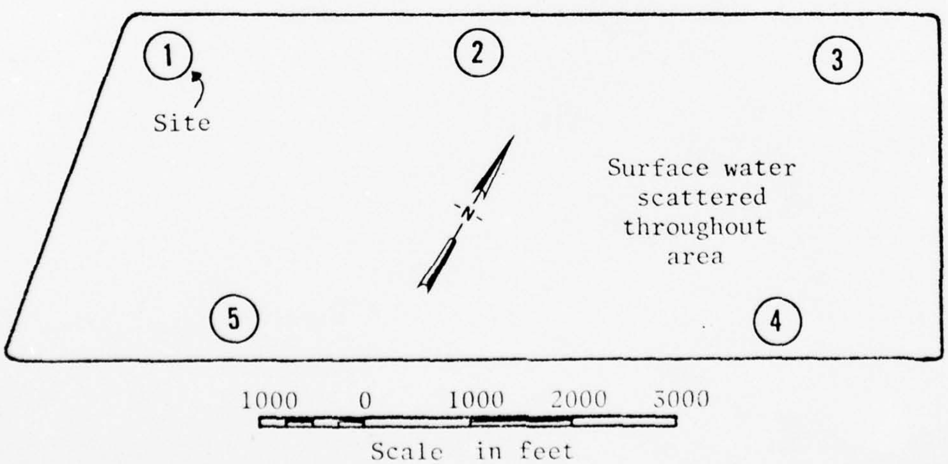
Area No.	Site No.	USCS Classification	Average Cone Index* 0-6	6-12	12-18	18-24	24-30	30-36	Remolding Index* 0-6	6-12	Rating Cone Index* 0-6	6-12	Moisture Content, % Dry Weight* 0-6	6-12	12-18	18-24	24-30	30-36	Dry Density, lb/ft³* 0-6	6-12	12-18	18-24	24-30	30-36
Detroit District																								
1	1	CH	1	0	1	2	2	2	+	+	+	+	47.3	98.4					62.6	43.7				
	2	CH	8	6	7	9	10	11	0.64	0.64	5	4	69.2	106.7					54.5	39.2				
	3	CH	11	5	7	14	32	55	0.46	0.64	5	3	65.9	70.0					56.6	52.1				
	4	CH	0	0	7	16	23	24	+	+	+	+												
	5	CH	6	4	7	12	20	30	0.64	0.64	4	3	95.3	88.6					42.4	46.2				
2	1	MH	69	84	83	90	98	110	0.62	0.60	43	50	31.0	39.1					70.0	71.0				
	2	MH	54	85	104	121	120	123	0.85	0.68	46	58	41.9	43.6					66.3	66.9				
	3	MH	48	76	105	129	160	213	0.51	0.60	24	46	32.3	36.7					81.9	72.7				
	4	MH	63	91	97	106	118	132	0.45	0.60	28	55	44.1	36.7					55.6	69.6				
	5	MH	64	76	92	103	109	116	0.62	0.60	40	46	40.7	42.7					67.4	69.3				
3	1	MH	51	26	20	26	42	58	0.62	0.76	32	20	45.9	62.2					61.8	56.0				
	2	MH	47	32	37	50	54	59	0.62	0.30	29	10	48.6	32.1					62.5	83.7				
	3	MH	28	9	11	18	20	20	0.74	0.45	21	4	66.6	81.3					46.6	46.8				
	4	MH	5	4	6	10	12	13	0.51	0.70	3	3	110.8	103.1					39.2	43.7				
4	1	CH	22	37	46	46	46	54	0.69	0.62	15	23	53.8	49.4					65.9	69.4				
	2	CH	25	48	52	59	60	60	0.50	0.72	12	35	55.9	54.7					59.8	64.8				
	3	CH	43	53	61	71	84	96	0.96	0.72	41	38	40.6	39.1					63.6	71.6				
	4	MH	57	78	89	98	100	101	0.93	0.94	53	73	31.5	42.8	41.9	51.1	54.7	62.2	70.6	64.4	63.1	67.6	65.3	56.7
	5	SM	59	77	83	88	101	110	2.84	1.25	168	96	14.8	28.4					86.2	83.8				
5	1	CH	22	53	121	243+	300+	300+	0.57	0.55	13	29	49.1	55.5					73.7	63.0				
	2	CH	9	26	39	52	62	80	0.42	0.45	4	12	47.6	41.0					69.5	74.2				
	3	CH	9	30	35	40	46	55	0.32	0.33	3	10	49.9	58.5					62.9	59.2				
Chicago District																								
1	1	ML	50	73	69	103	117	214	0.33	0.20	16	15	33.6	51.5					78.9	70.0				
	2	ML	54	74	65	61	80	112	0.16	0.38	9	28	45.8	80.8					74.0	53.0				
	3	ML	22	32	28	26	39	52	0.29	0.56	6	18	63.6	80.8					60.5	52.1				
	4	ML	41	71	70	74	84	96	0.60	0.54	25	38	34.1	30.6					87.6	89.8				
	5	ML	41	83	85	106	156	196	0.59	0.56	24	46	53.8	49.8					64.4	67.8				
	6	ML	25	43	72	85	75	63	0.38	0.24	10	10	83.8	59.2					50.5	63.4				
2	1	MH	75	87	139	165	143	117	0.69	0.48	31	42	49.7	50.7					68.1	66.5				
	2	SM	89	133	109	94	82	69	>1	>1	>89	>133	18.0	42.7	43.4	48.3	61.0	53.9	85.2	71.4	70.6	66.2	59.7	64.6
	3	SM	79	136	159	156	130	111	>1	>1	>79	>136	12.3	22.2					95.5	88.8				
	4	MH	48	55	27	28	32	35	0.26	0.27	12	15	45.4	52.6					73.2	64.5				
3	1	MH	35	45	66	110	164	246	0.96	0.89	32	40	50.7	53.6	64.7	62.1	56.8	33.2	64.2	64.6	57.4	59.7	64.7	
	2	MH	12	12	11	11	14	18	0.44	0.58	5	7	37.3	59.1					80.9	61.8				
	3	MH	49	51	42	41	44	44	0.83	0.60	41	31	44.4	48.5					68.5	70.4				
	4	MH	66	60	53	48	44	44	0.50	0.52	33	31	45.5	52.5					69.8	67.0				
	5	MH	17	18	13	12	13	15	0.49	0.58	8	10	63.0	67.6					56.4	57.2				
	6	MH	18	15	12	10	10	12	0.45	0.68	8	10	69.9	61.4					55.8	56.9				
New Orleans District																								
1	1	SP	220	441	305	281	343	462	-	-	-	-	14.4	26.5	27.4	28.4	37.9	20.9	93.1	86.7	85.6	90.9	77.0	93.2
2	1	SP	221	507	587	608	614	612	-	-	-	-	8.2	18.4	23.6	26.7	-	-	93.2	97.2	91.1	87.5		
3	1	ML	110	169	172	138	122	116	-	-	-	-	37.6	27.4	23.0	23.3	31.1	-	78.3	86.6	86.9	87.6	82.6	
4	1	SM	138	146	113	-	-	-	>1	>1	>138	>146	21.7	30.0	54.3	57.9	-	-	74.8	70.0	62.8	62.6	-	-
	2	CH	47	117	232	-	-	-	0.44	0.70	21	82	26.6	16.0	31.3	22.1	-	-	77.8	89.0	87.3	94.0	-	-
5	1	CH	33	27	40	50	41	34	0.74	0.82	24	22	83.3	59.8	29.5	40.9	52.5	58.1	46.9	60.2	85.5	76.0	67.2	66.3
	2	SM	257	499	328	166	104	102	>1	>1	>257	>499	2.3	3.2	7.0	6.6	-	-	95.1	98.0	-	-	-	-
6,7,8	1		**																					
9	1	SM	0	1	5	10	14	20	+	+	+	+	180.8	80.1	92.8	87.4	80.9	85.2	31.0	50.8	46.6	48.0	51.0	49.6
	2	SM	21	19	12	13	18	20	>1	>1	>21	>19	61.5	38.0	47.5	50.1	39.7	37.5	58.2	78.2	71.6	68.7	89.1	60.0
	3	SM	146	116	73	76	78	85	>1	>1	>146	>116	7.0	26.6	27.5	24.4	24.9	31.5	96.5	86.1	92.5	97.2	95.0	56.3
10	1	SM	145	231	175	136	122	126	>1	>1	>145	>231	25.5	50.8	176.8	147.6	125.6	113.8	95.6	66.3	26.8	31.4	36.0	-
Seattle District																								
1	1		**																					
2	1	OL	10	6	8	12	17	20	0.57	0.69	6	4	130.0	152.1	179.5	124.1	128.5	178.0	35.9	30.9	28.4	35.0	37.0	30.6
	2	OL	12	8	10	16	23	30	0.62	0.70	7	6	134.1	95.5	114.9	154.1	96.4	114.4	35.2	46.4	40.6	37.4	47.3	40.4
3	1	OL	12	12	14	18	23	26	0.60	0.60	7	7	149.0	133.4	118.1	143.2	104.5	85.5	31.4	35.9	39.4	52.0	43.0	[illegible]
	2	OL	23	12	15	++	-	-	0.54	0.70	7	8	87.2	121.5	197.3	-	-	-	48.2	38.1	28.3	-	-	-
4	1	SP	179	530	725	750+	750+	750+	>1	>1	-	-	4.5	4.4	-	-	-	-	91.8	97.5	-	-	-	-
5	1	ML	53	37	36	68	70	62	0.60	0.98	32	36	59.6	31.4	107.6	81.4	66.3	73.8	58.5	77.7	42.5	50.9	56.2	-
	2	SM	16	43	64	131	250	281	>1	>1	-	-	50.7	51.0	45.9	44.5	-	-	62.5	64.2	72.6	-	-	-
	3	ML	9	8	12	18	32	48	0.63	0.59	6	5	122.9	167.1	151.0	164.5	107.4	161.2	38.5	32.0	33.1	30.2	26.1	-
6	1	ML	15	31	35	29	26	25	0.39	0.41	6	13	99.8	60.8	64.0	71.0	75.7	84.3	44.1	61.8	60.6	50.2	52.2	43.2
	2	ML	14	13	26	43	39	38	0.39	0.41	5	5	81.9	87.9	109.4	101.2	93.4	87.9	50.0	48.4	41.0	44.3	44.7	43.5
Philadelphia District																								
1	1	MH	17	4	5	7	11	16	0.66	0.41	11	2	106.4	124.5	87.4	90.4	107.9	102.8	40.7	34.9	45.5	45.6	34.4	34.6
	2	MH	14	8	9	12	16	21	0.52	0.46	7	4	85.8	68.6	86.2	108.6	83.0	129.3	43.4	55.5	45.5	40.3	47.3	56.0
	3	ML	260	142	134	126	155	179	0.37	0.41	101	58	43.7	62.0	52.3	47.4	76.0	61.8	59.2	55.7	62.7	66.2	55.4	43.2
2	1	MH	48	57	78	74	76	82	0.62	0.60	30	34	74.3	89.2	73.1	78.5	100.5	56.9	42.4	38.3	53.9	52.0	36.3	34.7
	2	MH	28	17	11	12	16	22	0.63	0.71	18	12	129.3	147.2	170.5	189.5	184.4	169.9	32.6	31.9	27.8	25.8	25.4	24.4
	3	ML	135	205	189	138	108	105	0.39	0.41	53	84	44.6	20.6	12.3	32.5	16.8	49.4	51.2	79.0	99.2	78.8	90.7	64.4
	4	ML	186	238	253	173	133	168	0.39	0.41	73	98	3.3	11.4	9.7	-	-	-	85.8	78.4	99.5	-	-	-

(Continued)

* Layer depths are in inches.
** No data. Dredged material being pumped into disposal area or area flooded.
\+ Soil too soft to conduct remolding test.
\+\+ Bottom of fill area (not dredged material).

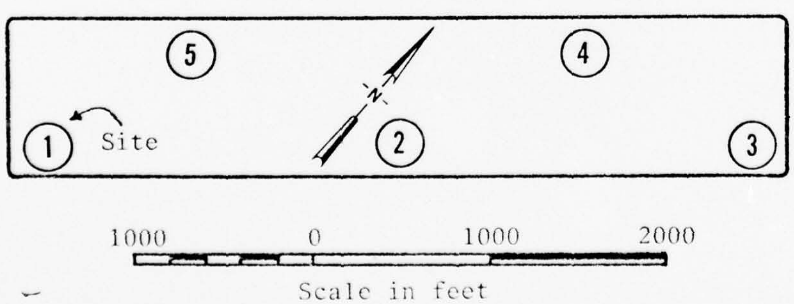
Table A2 (Concluded)

Area No.	Site No.	USCS Classi-fication	Average Cone Index* 0-6	6-12	12-18	18-24	24-30	30-36	Remolding Index* 0-6	6-12	Rating Cone Index* 0-6	6-12	Moisture Content, % Dry Weight 0-6	6-12	12-18	18-24	24-30	30-36	Dry Density, lb/ft³* 0-6	6-12	12-18	18-24	24-30	30-36
													Philadelphia District (Continued)											
3	1	MH	2	23	60	78	74	74	0.62	0.60	1	14	105.8	82.5	76.6	-	-	-	43.0	45.1	51.6	-	-	-
	2	MH	39	59	65	66	60	64	0.54	0.60	21	35	101.0	103.0	97.0	97.9	97.4	98.8	41.0	43.2	40.3	43.0	45.5	40.2
4	1	ML	40	199	385	405	405	373	0.39	0.41	16	82	39.0	30.5	23.9	-	-	-	55.1	66.8	-	-	-	-
5	1	MH	52	50	68	69	55	42	0.76	0.70	40	35	74.7	81.5	66.5	74.5	83.4	95.5	43.0	42.8	45.8	50.7	47.6	44.2
	2	MH	194	84	81	133	168	184	0.68	0.73	132	61	59.9	89.9	89.1	64.6	55.9	61.9	50.0	45.0	**	56.7	61.6	58.6
6	1	MH	9	35	44	26	27	27	0.44	0.42	4	15	48.9	52.1	94.6	77.6	79.4	85.2	69.6	66.5	45.8	52.9	50.8	48.1
	2	SM	302	645	750+	750+	750+	750+	>1	>1	>302	>645	18.4	38.6	-	-	-	-	105.7	-	-	-	-	-
	3	MH	6	133	567	750+	750+	750+	0.46	0.60	3	80	94.6	14.2	-	-	-	-	46.2	91.3	-	-	-	-
	4	SM	121	244	404	579	690	750+	>1	>1	>121	>244	6.9	7.5	6.9	6.7	3.4	4.5	99.2	93.3	90.4	96.8	98.1	98.6
7	1	MH	48	64	64	48	37	32	0.52	0.50	25	32	90.4	60.2	74.8	65.0	86.1	99.2	40.3	58.2	51.5	55.1	48.4	43.6
	2	SM	269	619	750+	750+	750+	750+	>1	>1	>269	>619	11.9	20.3	-	-	-	-	96.8	92.6	-	-	-	-
	3	MH	204	313	406	564	663	720	0.67	1.50	137	470	35.7	16.9	13.1	10.6	14.4	-	62.4	83.2	94.4	102.7	94.0	-
													Galveston District											
1	1		**																					
	2	CH	10	19	26	28	29	25	0.60	0.88	6	17	93.7	58.8	51.3	59.1	69.1	99.8	49.9	63.0	69.0	62.8	57.8	46.3
	3	CH	89	60	19	32	48	54	0.94	0.52	84	31	8.4	29.3	73.9	58.3	55.6	57.6	98.9	87.0	64.6	64.0	66.6	-
2	1	CH	88	72	104	130	130	126	1.34	0.74	118	53	24.6	54.6	84.5	54.5	61.5	65.3	77.6	66.8	49.9	64.0	62.2	-
3	1	CH	35	27	18	36	54	50	0.69	0.92	24	25	76.6	71.2	102.0	69.8	77.7	83.1	50.3	55.3	44.0	57.8	53.4	50.3
	2	CH	32	16	32	38	31	46	0.74	0.89	24	14	55.9	98.4	52.7	81.9	91.9	47.5	63.6	45.3	67.7	51.6	47.5	69.6
	3	CH	38	12	24	30	24	28	0.78	0.92	30	11	47.1	136.6	80.9	101.5	104.2	102.9	57.6	33.1	52.1	44.8	43.5	43.6
4	1	CL	6	11	25	38	30	26	0.57	0.50	3	6	45.5	108.7	105.1	94.4	88.1	76.1	70.1	41.3	42.6	47.3	47.0	55.2
5	1	CL	2	3	9	30	48	54	0.56	0.57	1	2	49.4	100.4	86.9	-	-	-	66.7	38.4	45.2	-	-	-
6	1	CL	11	17	18	23	24	24	0.62	0.76	7	13	58.8	56.7	50.0	60.3	53.2	47.3	34.8	58.4	71.6	61.1	66.8	73.0
	2	CL	15	24	30	34	35	34	0.58	0.61	9	15	97.7	42.4	42.0	39.7	38.2	36.3	35.5	76.3	75.2	80.3	82.6	83.8
7	1	CL	9	9	9	8	8	10	0.58	0.61	5	5	43.9	57.8	38.2	35.0	38.9	56.1	70.4	58.3	79.9	75.5	62.5	58.2
8	1		**																					-
9	1	CH	5	20	32	31	29	-	0.32	0.85	2	17	124.4	71.2	58.9	67.5	-	-	35.7	55.5	63.7	58.6	-	-
10	1	CH	18	27	23	25	31	36	0.64	0.64	12	17	82.9	59.5	62.5	84.1	75.3	74.7	49.9	63.5	61.8	49.9	54.1	54.2
11	1	CH	7	14	16	13	19	24	0.72	0.64	5	9	80.7	26.5	66.6	33.9	39.7	39.2	50.6	92.0	53.3	82.8	77.4	72.0
	2	CH	42	75	47	66	28	36	0.90	1.26	38	95	31.2	19.6	41.1	32.2	38.8	49.3	76.6	88.3	76.2	87.4	78.3	70.5
12	1	CH	9	6	7	10	14	18	0.78	0.38	7	2	85.1	89.7	125.5	124.7	124.4	119.5	51.2	46.2	36.8	37.3	37.0	40.0
	2	CH	7	7	8	10	13	15	0.67	0.50	5	4	68.6	98.9	112.1	113.1	114.7	107.2	55.3	44.2	37.3	38.9	40.0	40.5
	3	CH	6	4	5	7	10	14	0.65	0.38	4	2	72.0	136.4	122.8	115.3	133.3	119.9	55.8	35.5	35.9	40.4	36.5	39.8
13	1	CH	25	20	37	38	43	45	0.64	0.64	16	13	54.6	62.8	67.0	72.5	70.7	77.2	42.3	54.0	53.9	54.0	52.3	54.6
14	1		**																					-
													Mobile District											
1	1	CH	28	13	11	12	14	16	0.60	0.57	17	7	130.9	137.2	-	-	-	-	34.5	32.0	-	-	-	-
	2	CH	12	8	6	6	8	9	0.56	0.54	7	4	131.3	190.7	-	-	-	-	32.4	24.2	-	-	-	-
	3	CH	5	5	5	4	4	4	0.64	0.64	3	3	-	-	-	-	-	-	-	-	-	-	-	-
	4	CH	11	5	6	6	8	9	0.64	0.64	7	3	150.7	196.2	155.9	152.9	-	-	30.3	23.5	29.0	28.4	-	-
2	1	CH	16	5	5	7	9	12	0.64	0.64	10	3	-	-	-	-	-	-	-	-	-	-	-	-
	2	CH	24	10	11	28	82	90+	0.64	0.64	15	6	-	-	-	-	-	-	-	-	-	-	-	-



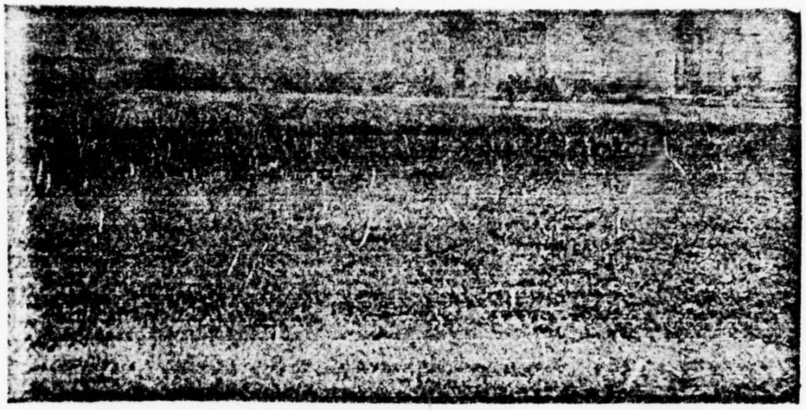
Detroit District
Area 1
Toledo, Ohio

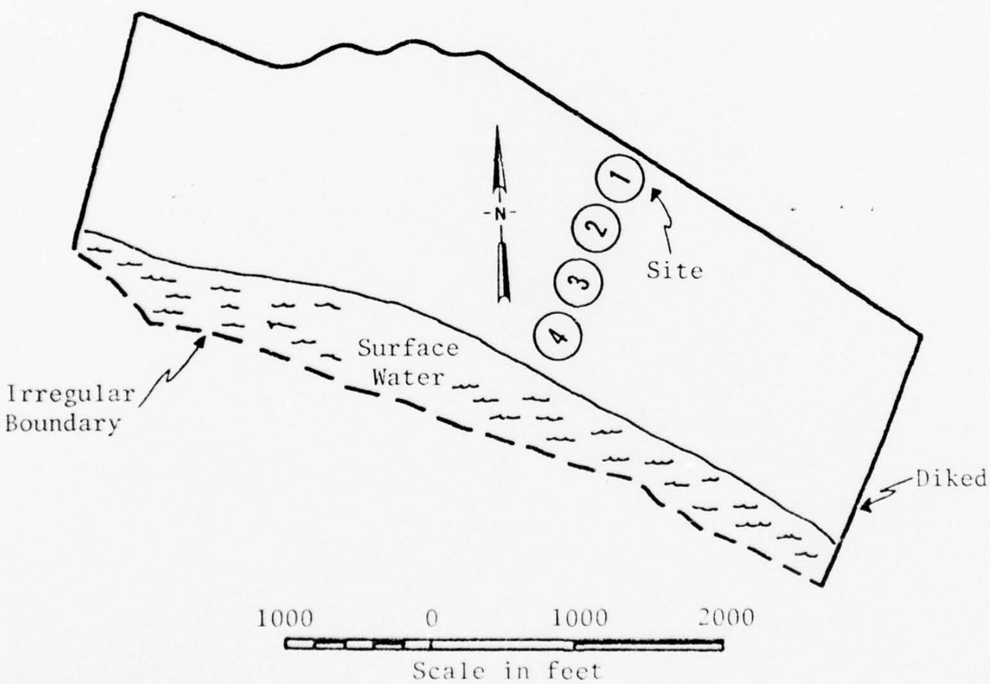
PLATE A1



Detroit District
Area 2
Toledo, Ohio

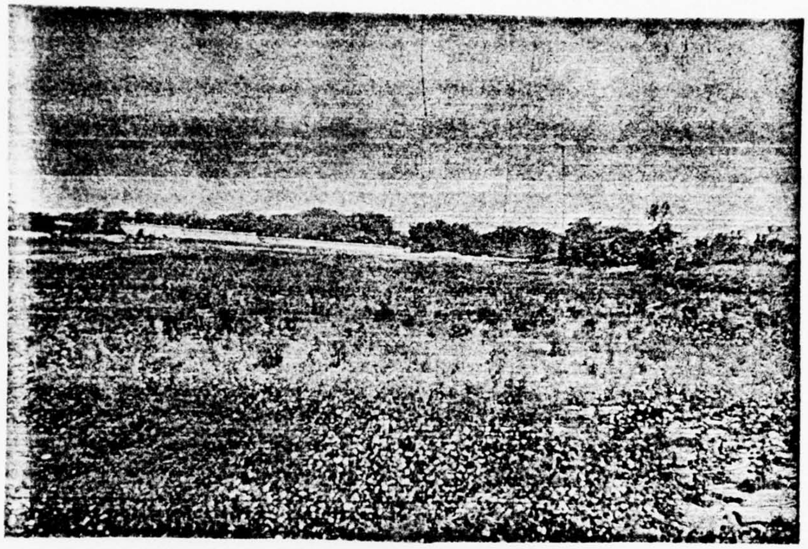
PLATE A2

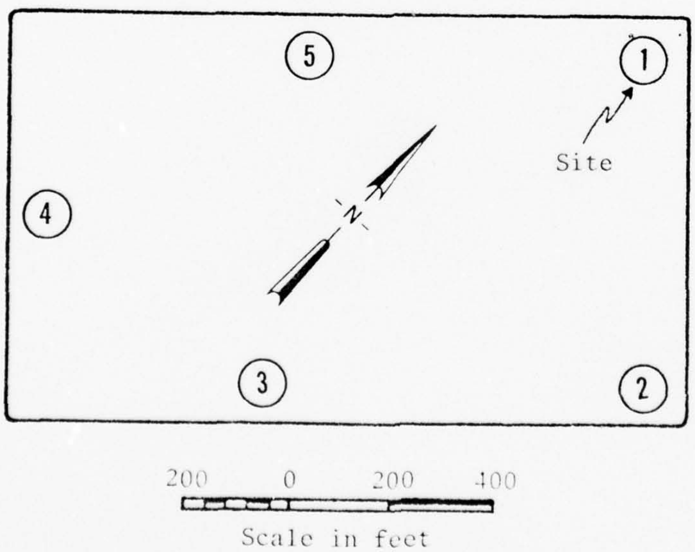




Detroit District
Area 3
Monroe, Michigan

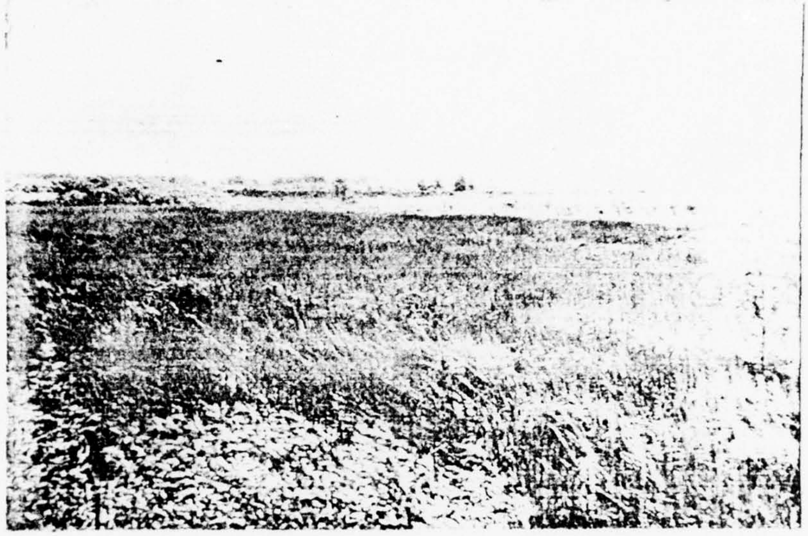
PLATE A3

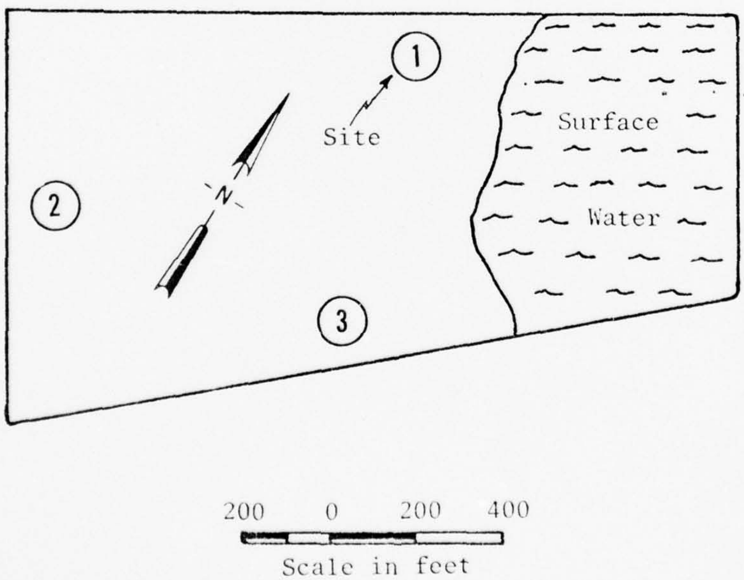




Detroit District
Area 4
Toledo, Ohio

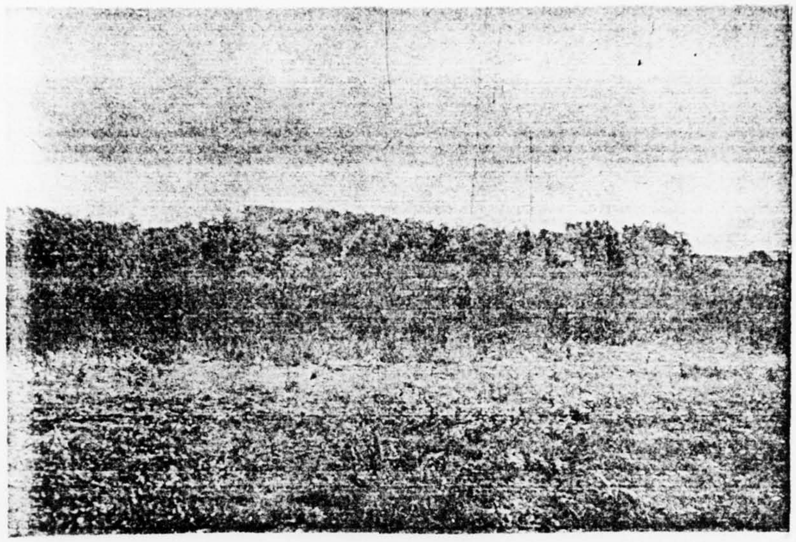
PLATE A4

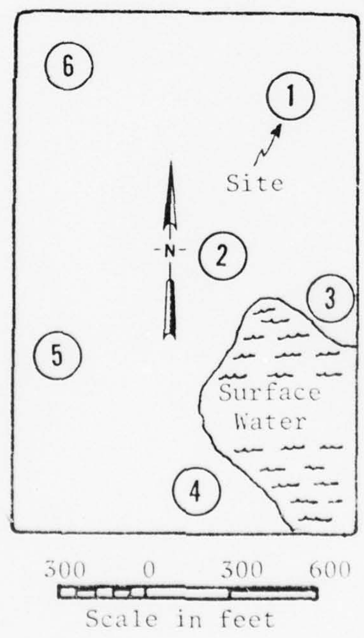




Detroit District
Area 5
Toledo, Ohio

PLATE A5





Chicago District
Area 1
Stoney Island

PLATE A6

AD-A044 209 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/3
LOW-GROUND-PRESSURE CONSTRUCTION EQUIPMENT FOR USE IN DREDGED M--ETC(U)
AUG 77 W E WILLOUGHBY

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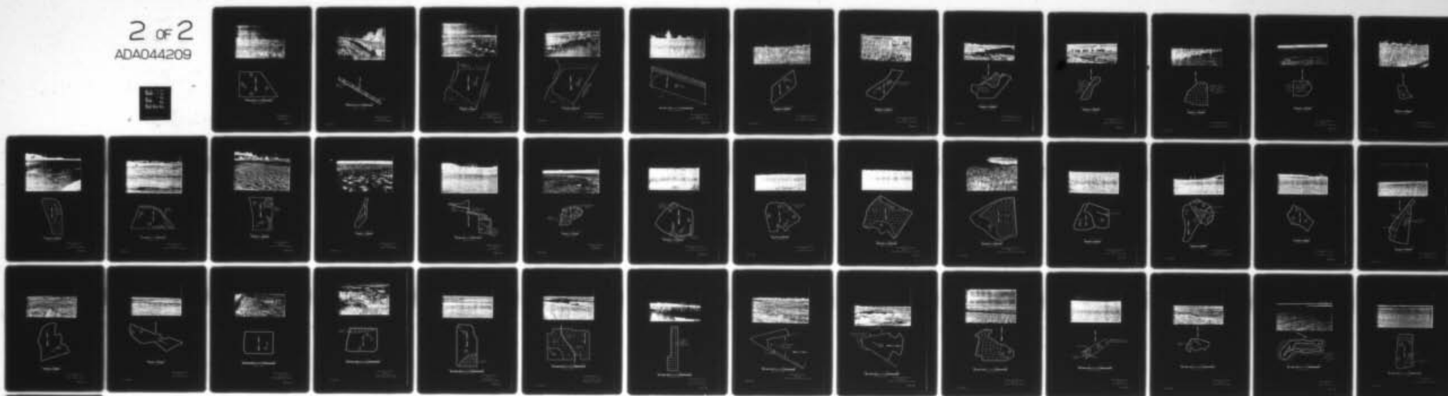

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DATE
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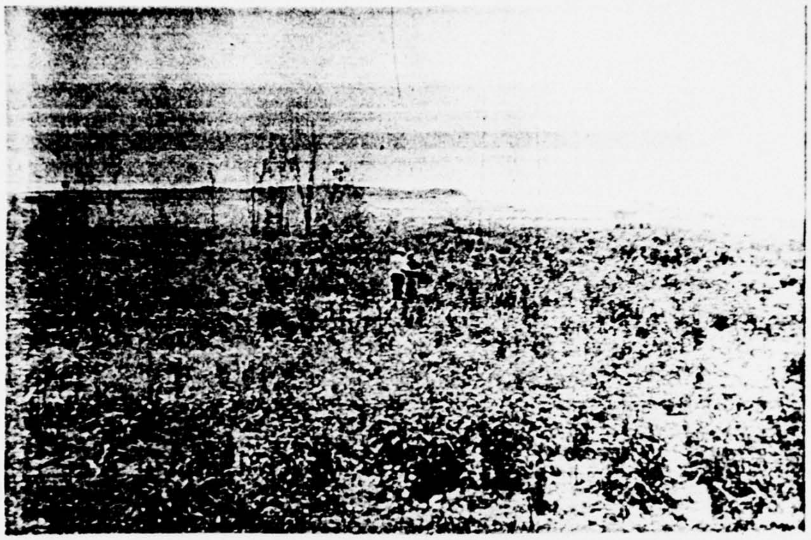
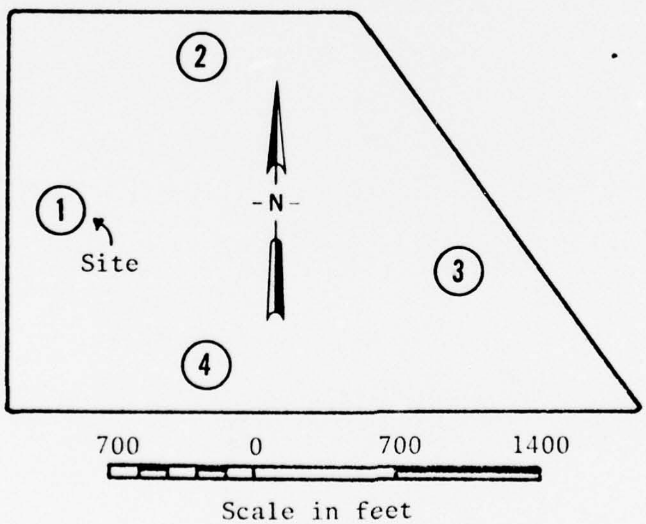
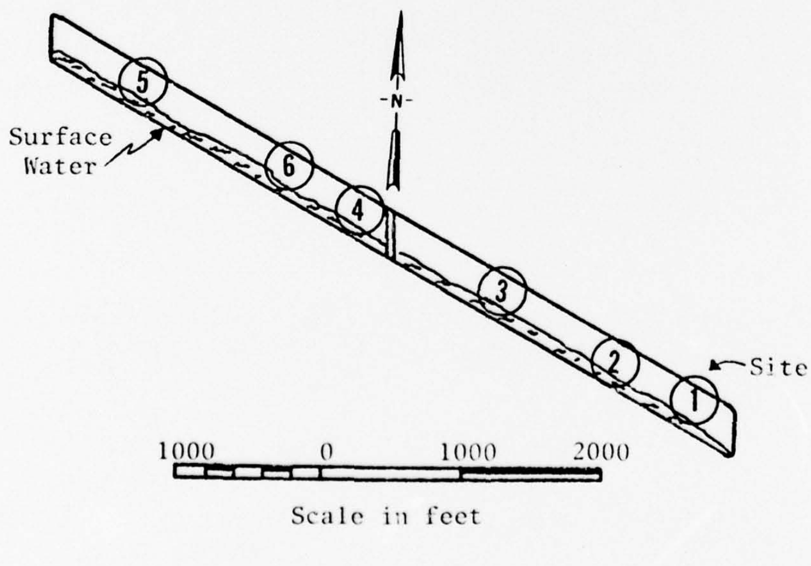




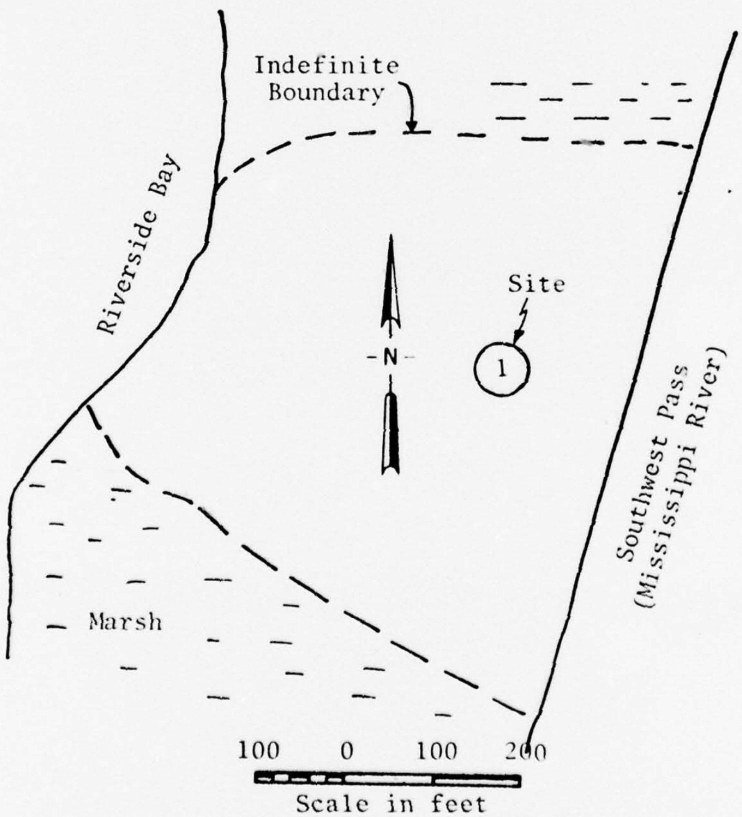
Chicago District
Area 2
O'Brien Lock

PLATE A7



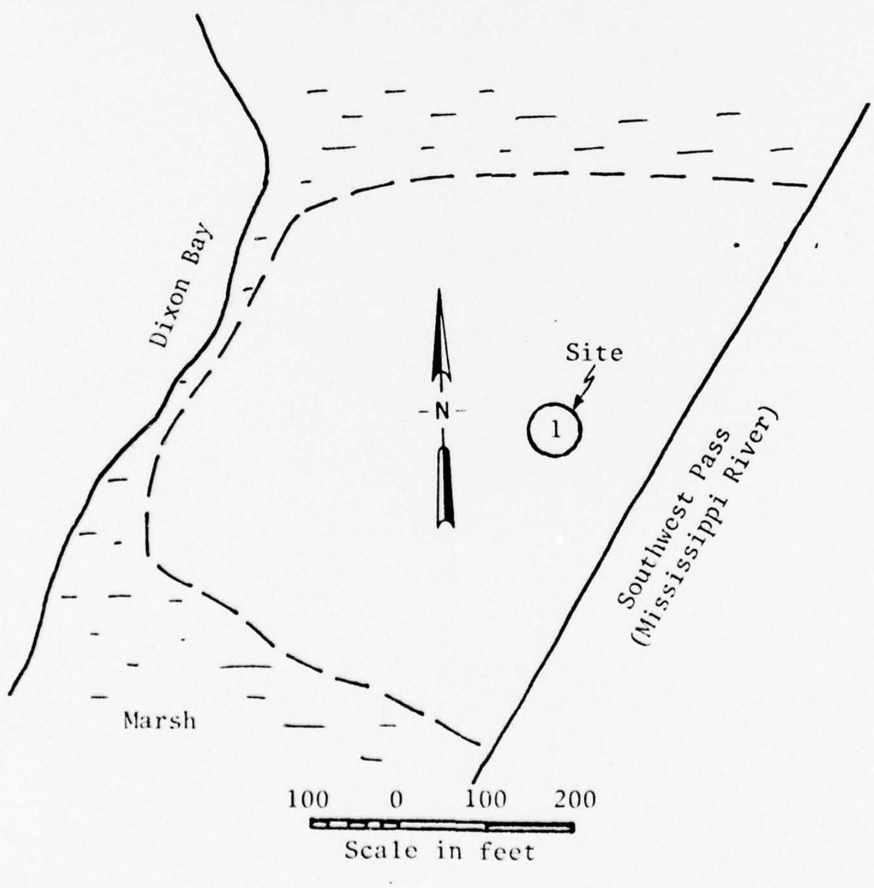
Chicago District
Area 3
Calumet Sag Channel

PLATE A8



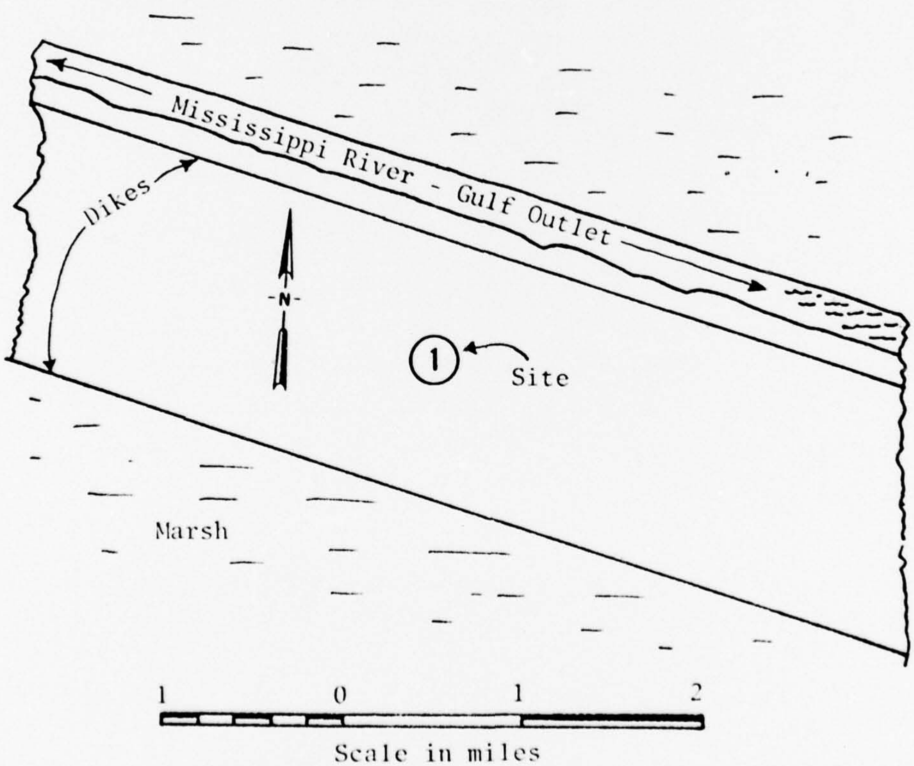
New Orleans District
Area 1
Lower Mississippi River

PLATE A9



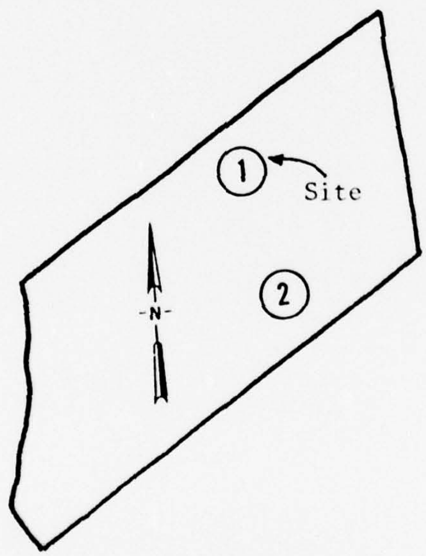
New Orleans District
Area 2
Lower Mississippi River

PLATE A10



New Orleans District
Area 3
Along Shipping Lanes

PLATE A11

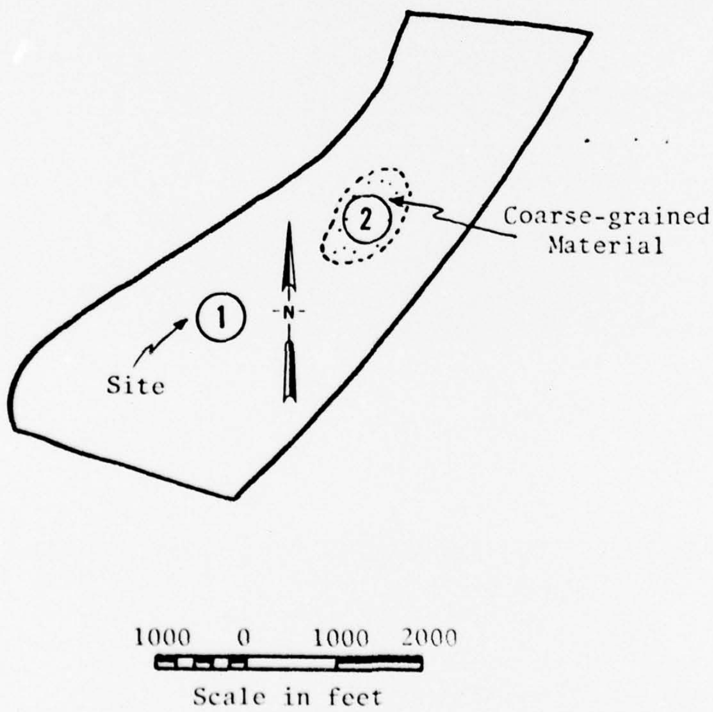


1000 0 1000 2000

Scale in feet

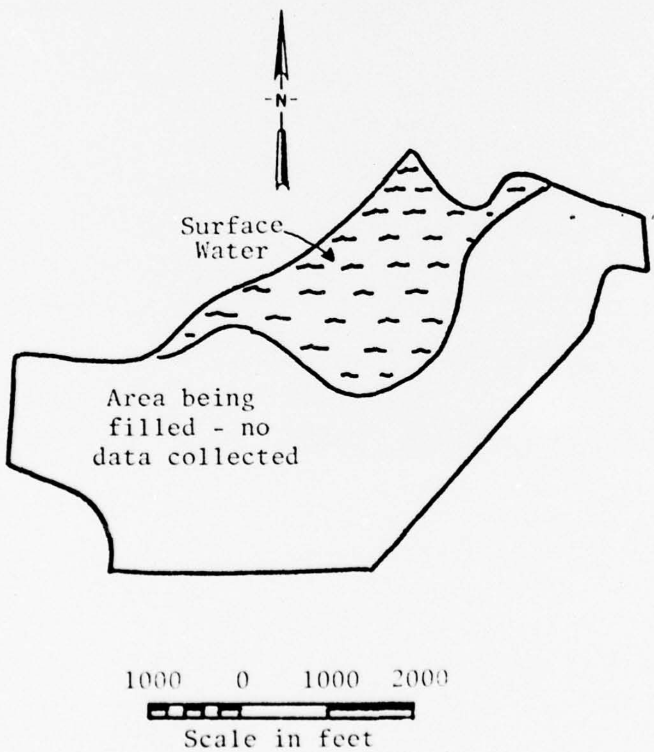
New Orleans District
Area 4
Lake Charles, Louisiana

PLATE A12



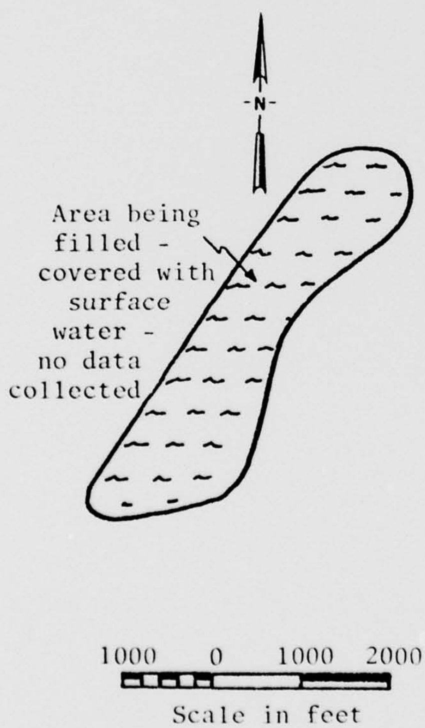
New Orleans District
Area 5
Lake Charles, Louisiana

PLATE A13



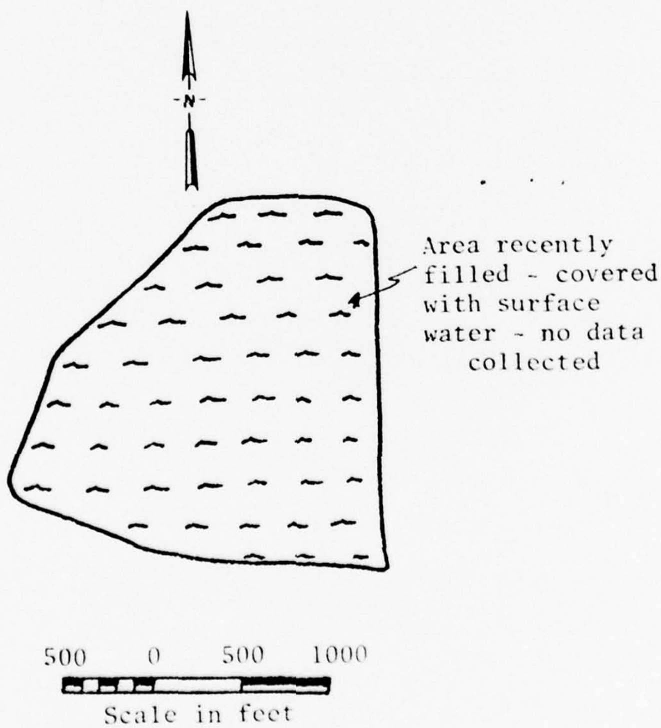
New Orleans District
Area 6
Along Calcasieu River

PLATE A14



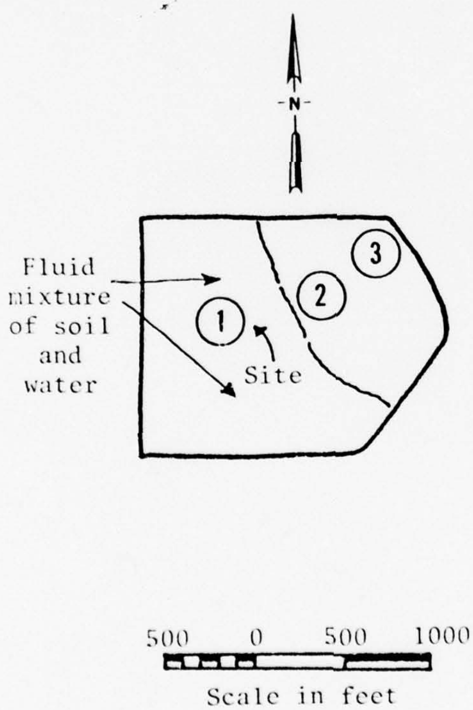
New Orleans District
Area 7
Along Calcasieu Channel

PLATE A15



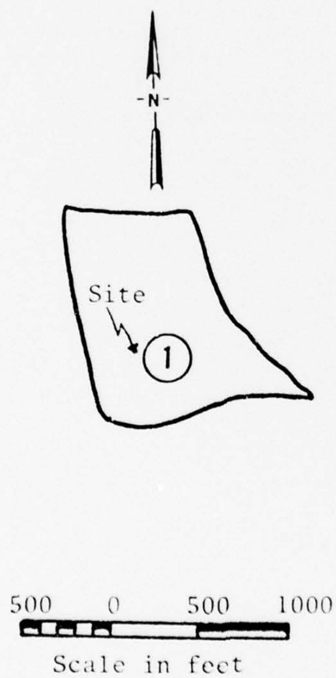
New Orleans District
Area 8
Along Calcasieu Channel

PLATE A16.



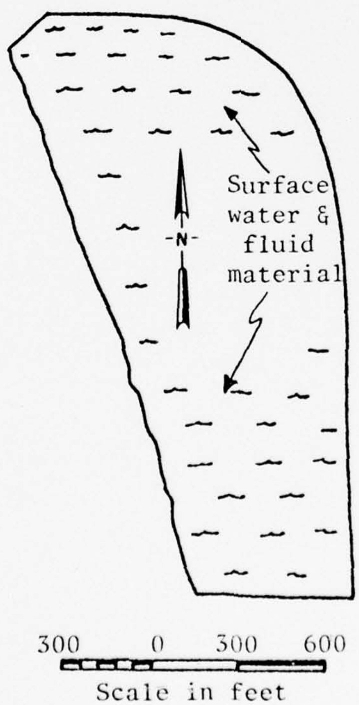
New Orleans District
Area 9
Lake Charles, Louisiana

PLATE A17



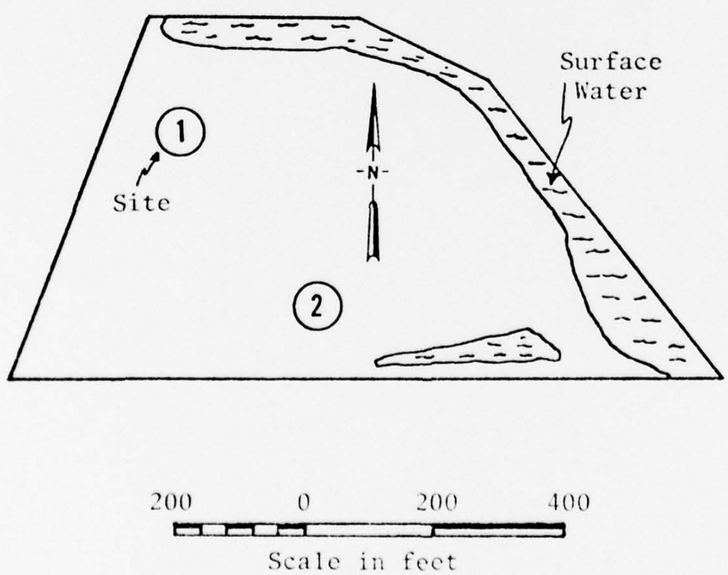
New Orleans District
Area 10
Lake Charles, Louisiana

PLATE A18



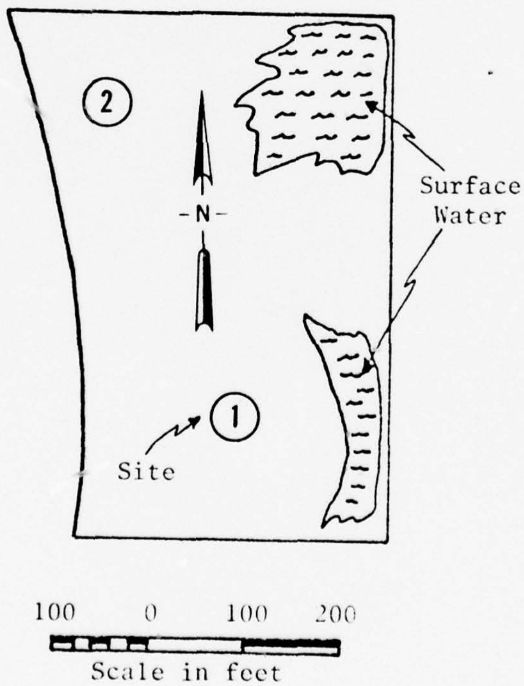
Seattle District
Area 1
Anacortes, Washington

PLATE A19



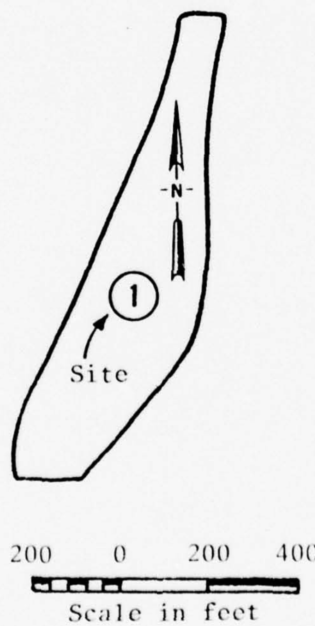
Seattle District
Area 2
Capsante Waterway Project

PLATE A20



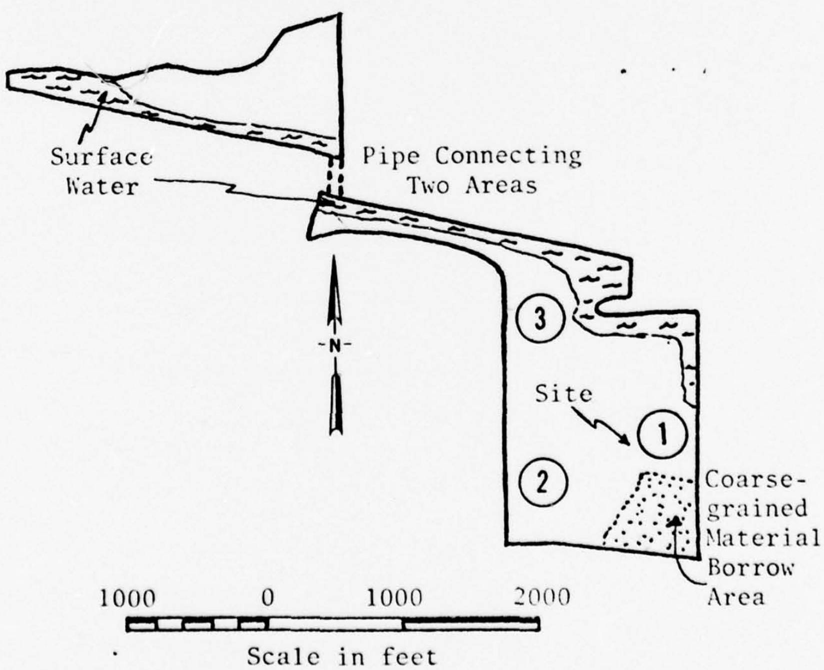
Seattle District
Area 3
Capsante Waterway Project

PLATE A21



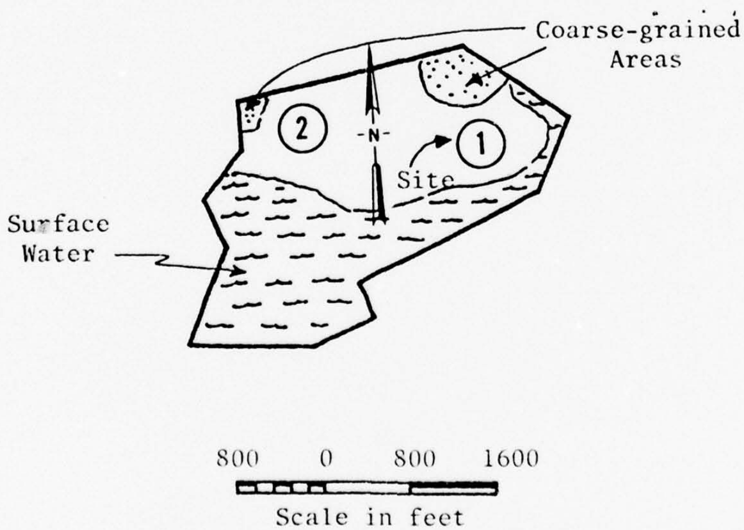
Seattle District
Area 4
Everett, Washington

PLATE A22



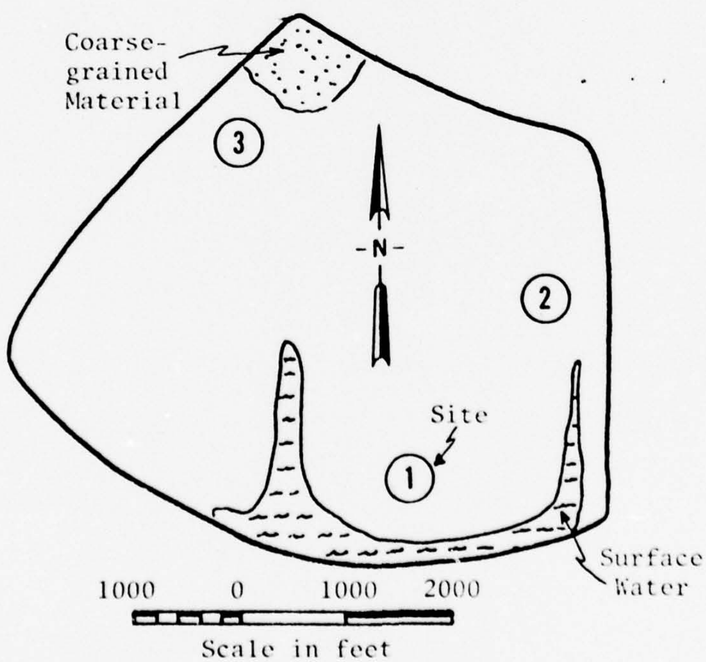
Seattle District
Area 5
Grays Harbor

PLATE A23



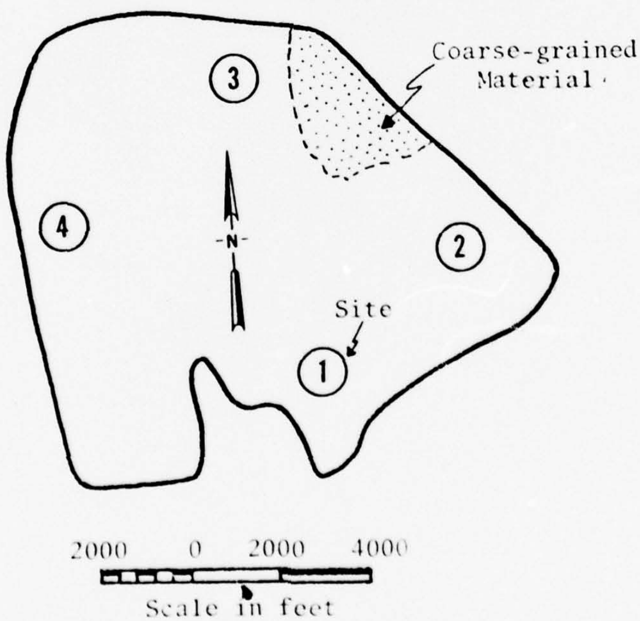
Seattle District
Area 6
Grays Harbor

PLATE A24



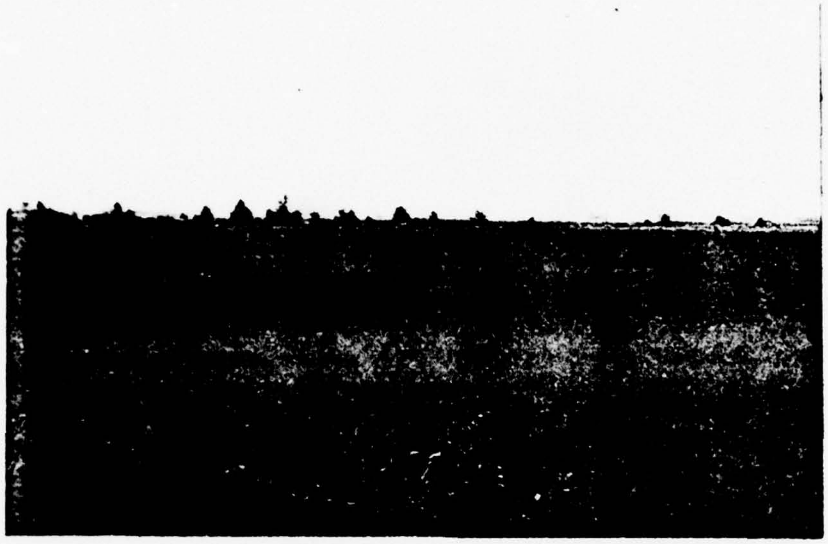
Philadelphia District
Area 1
Penn's Neck, New Jersey

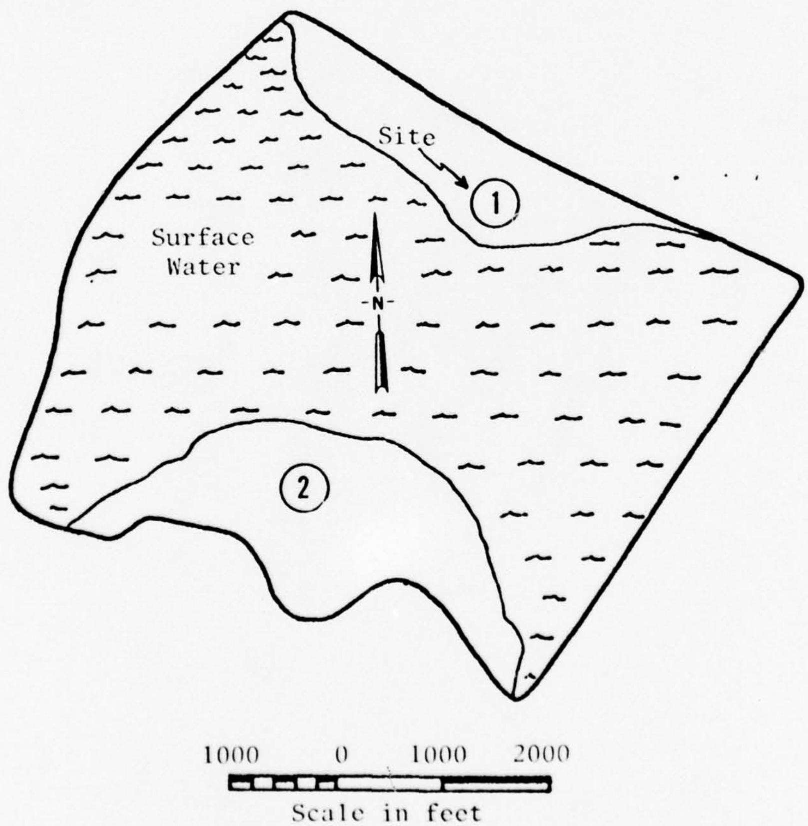
PLATE A25



Philadelphia District
Area 2
Fort Mott, New Jersey

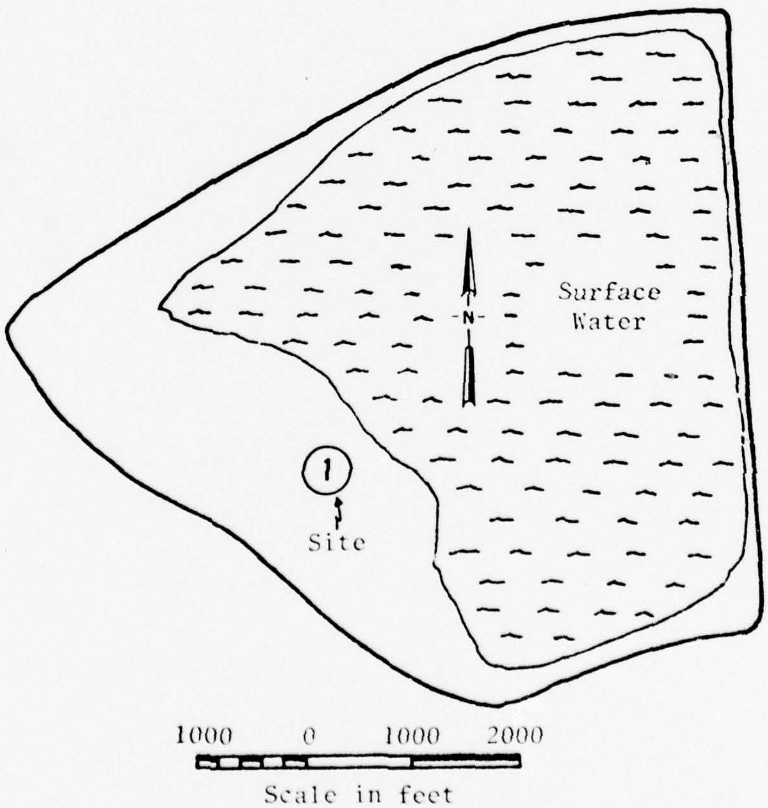
PLATE A26





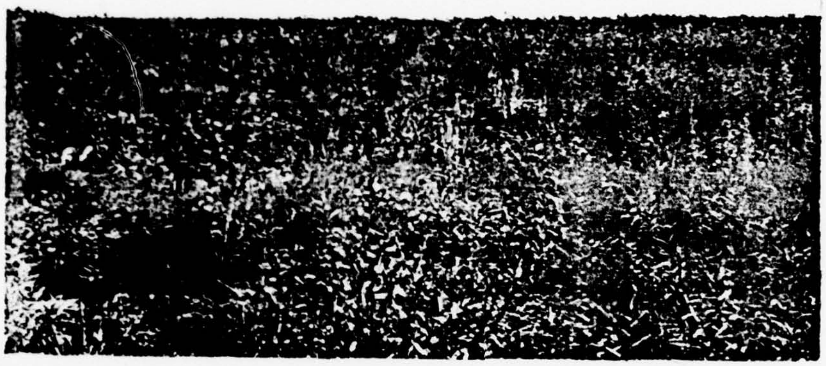
Philadelphia District
Area 3
Pedricktown, New Jersey (South)

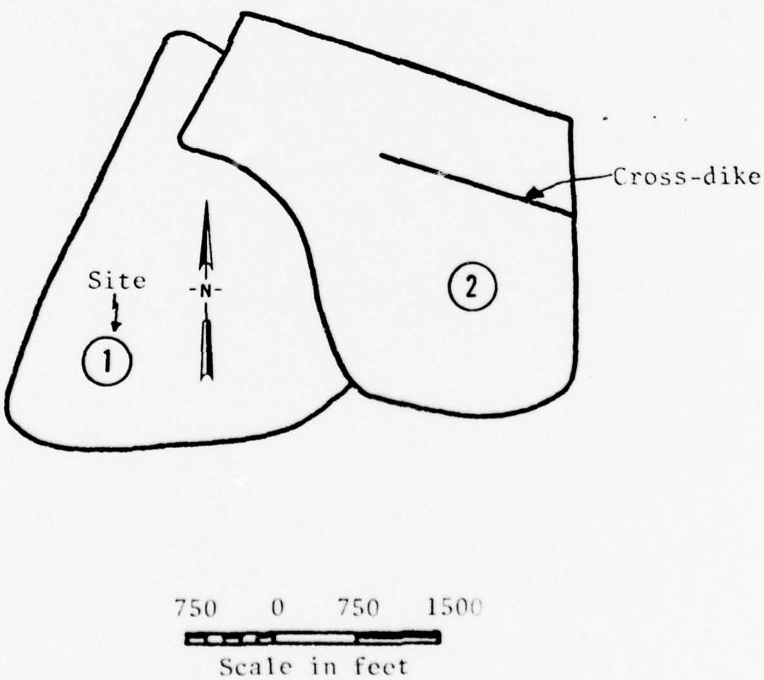
PLATE A27



Philadelphia District
Area 4
Pedricktown, New Jersey (North)

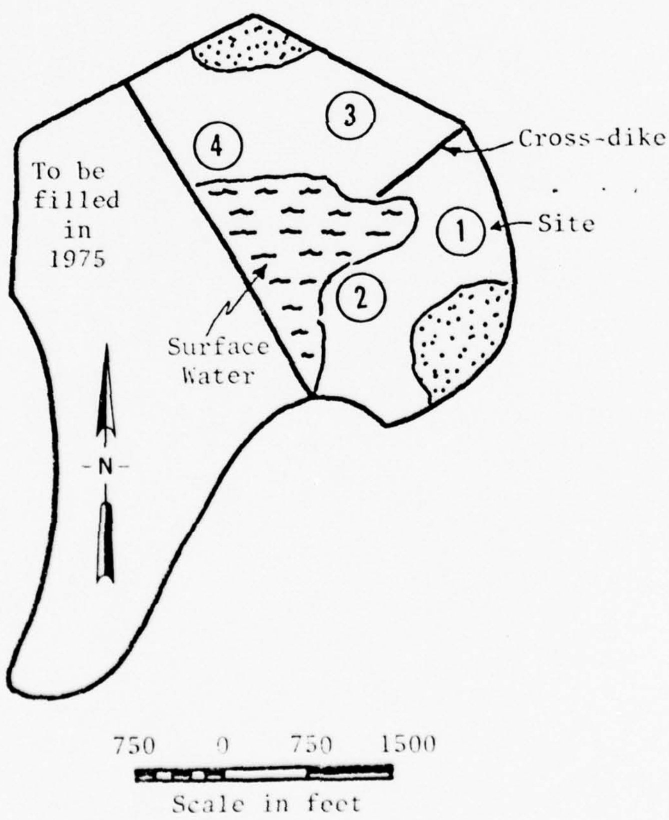
PLATE A28





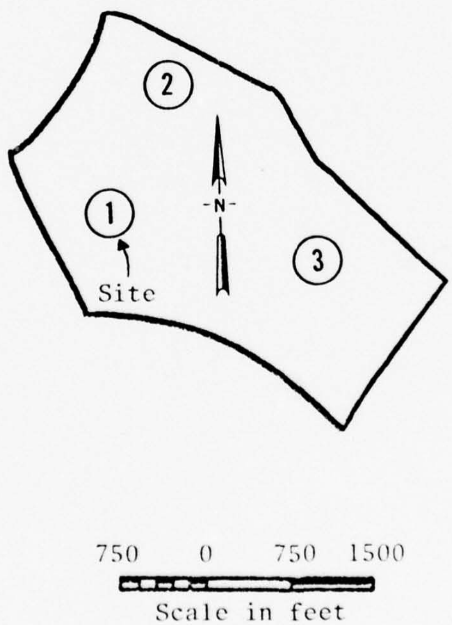
Philadelphia District
Area 5
Cherry Island, Delaware

PLATE A29



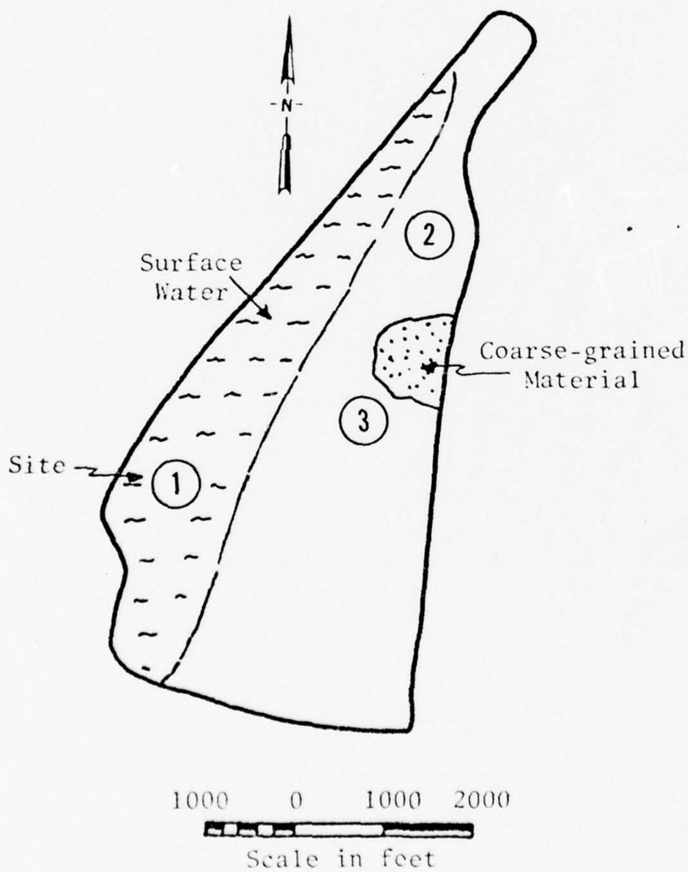
Philadelphia District
Area 6
Fort Mifflin, Pennsylvania

PLATE A30



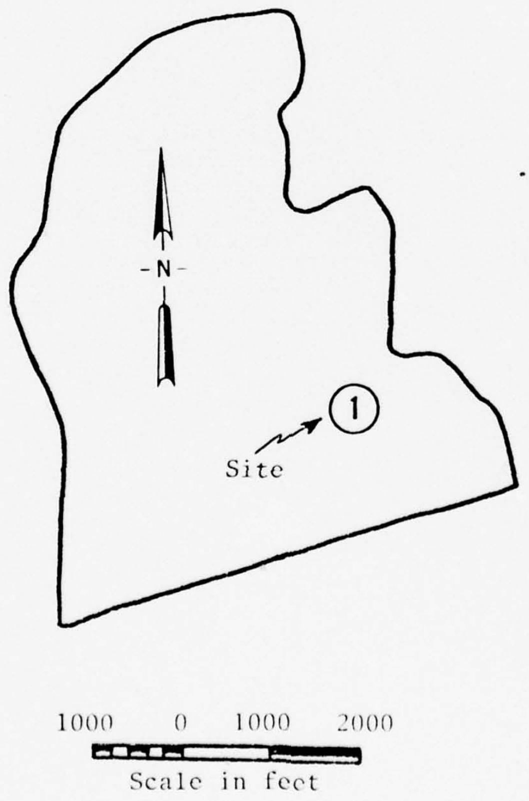
Philadelphia District
Area 7
National Park, New Jersey

PLATE A31



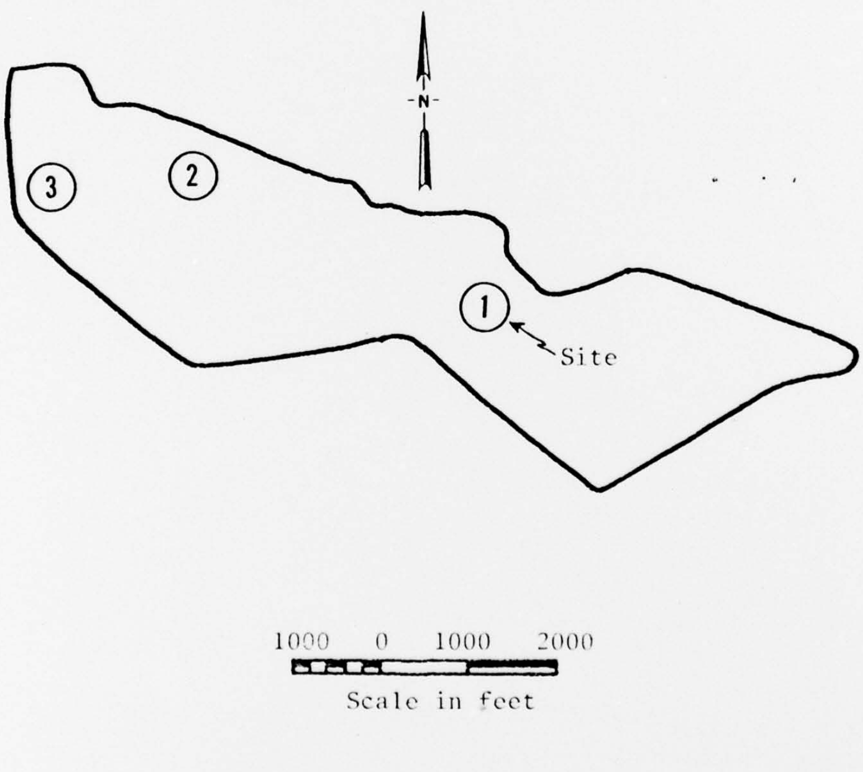
Galveston District
Area 1
Port Arthur, Texas

PLATE A32



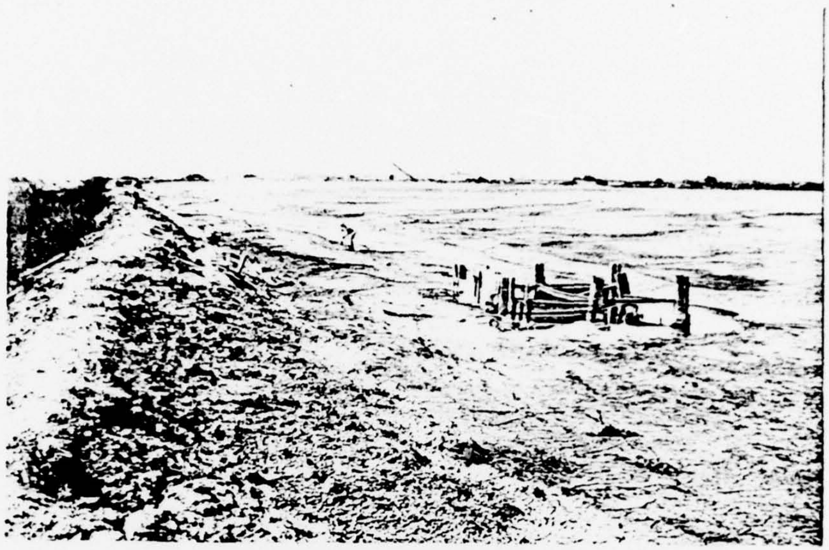
Galveston District
Area 2
Port Arthur, Texas

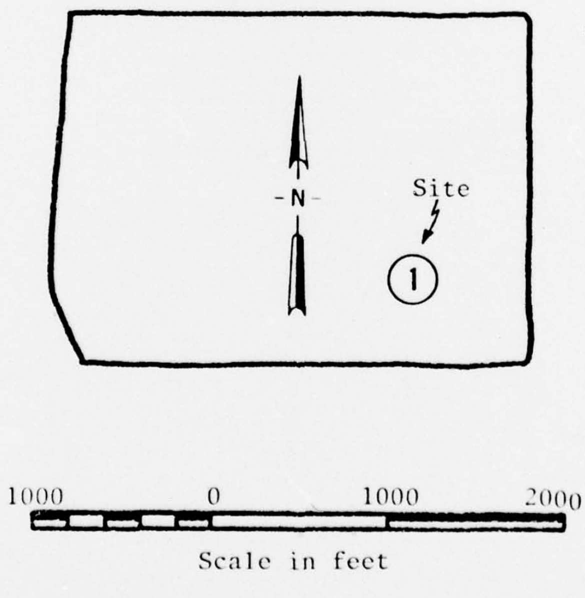
PLATE A33



Galveston District
Area 3
Port Arthur, Texas

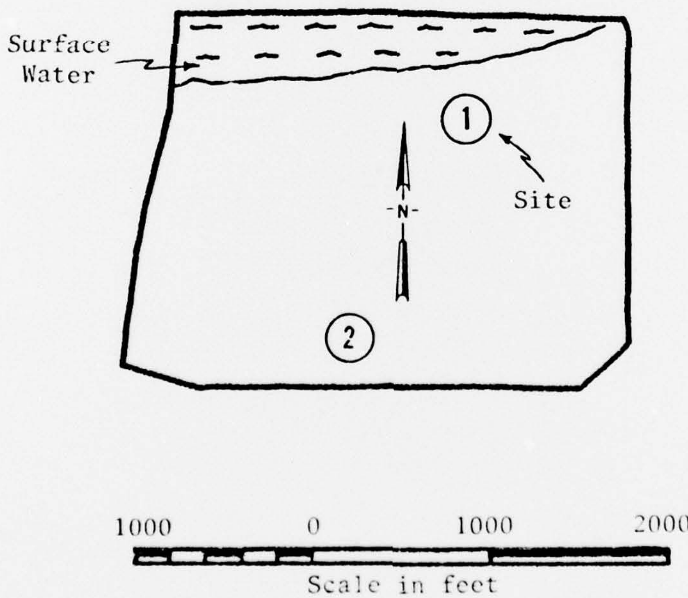
PLATE A34





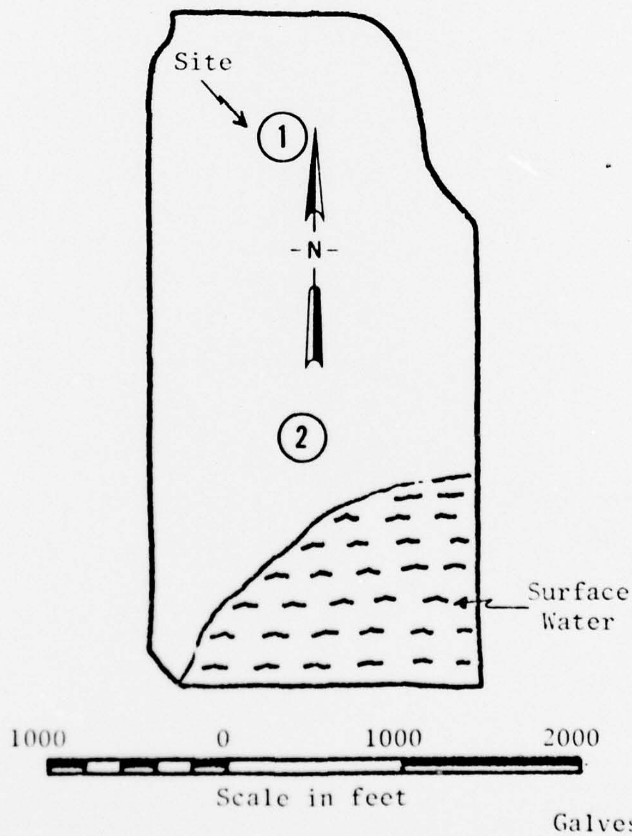
Galveston District
Area 4
West Jones North Cell
East of Houston, Texas

PLATE A35



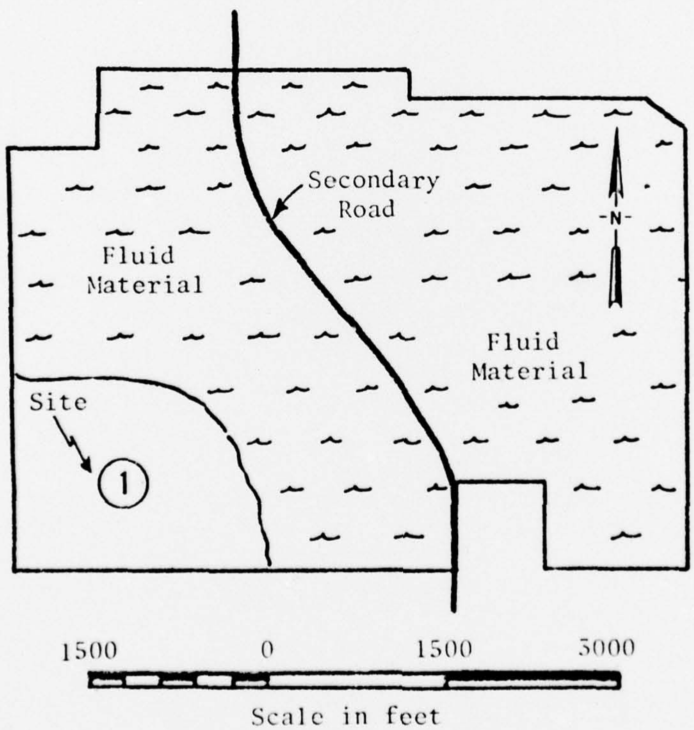
Galveston District
Area 5
West Jones South Cell
East of Houston, Texas

PLATE A36



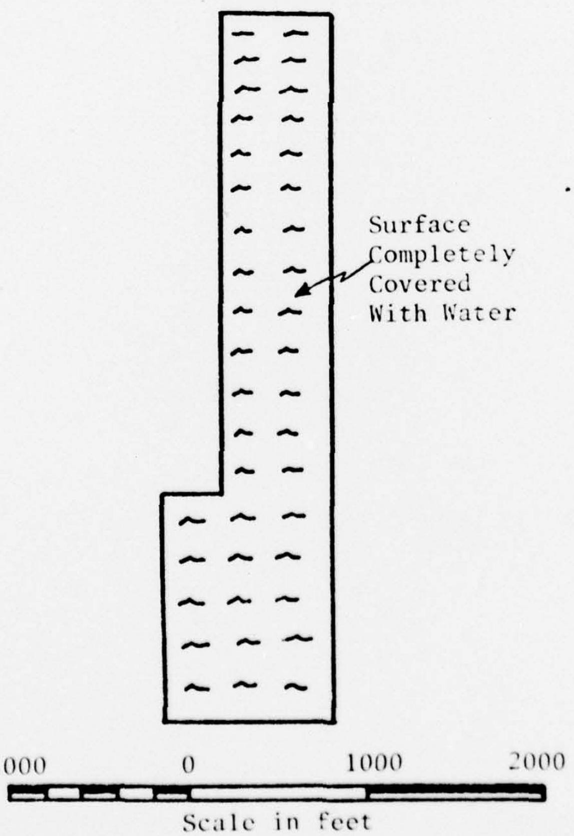
Galveston District
Area 6
East Jones Cell
East of Houston, Texas

PLATE A37



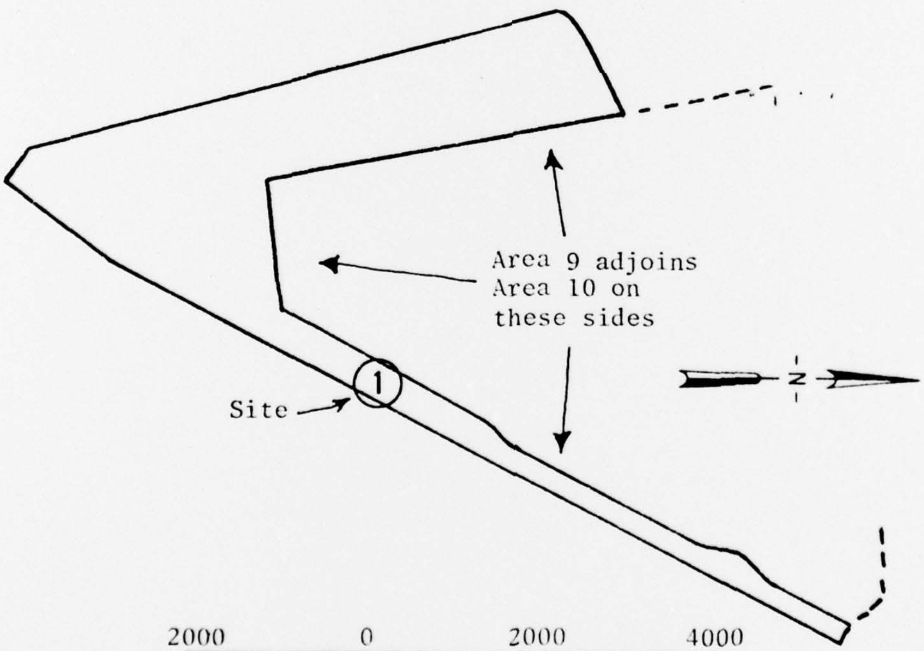
Galveston District
Area 7
Clinton Disposal Area
Galena Park, Texas

PLATE A38



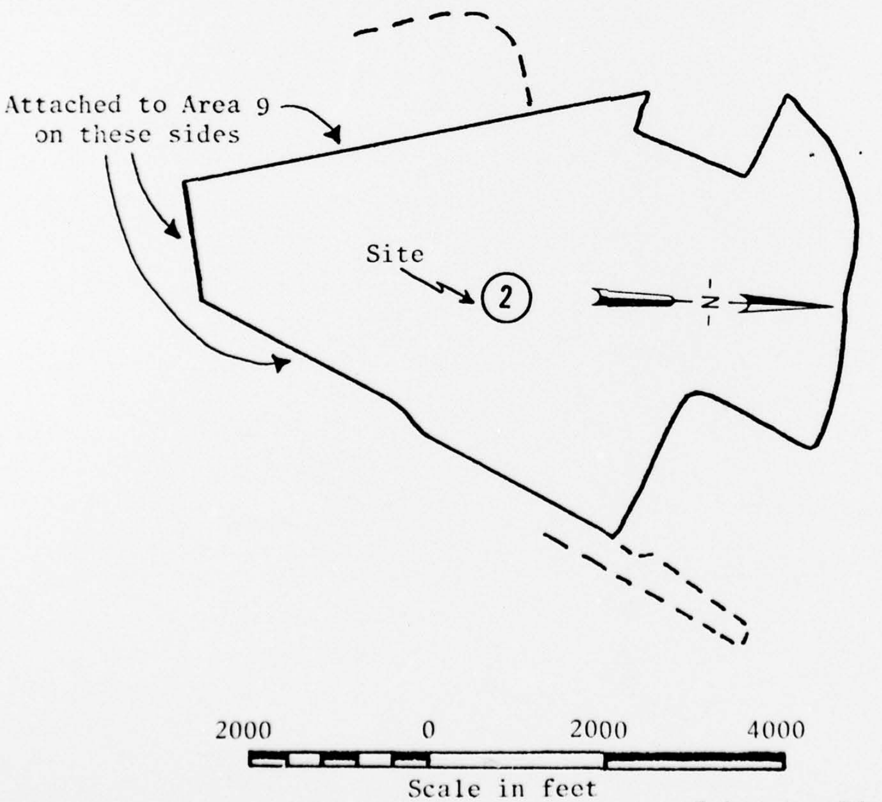
Galveston District
Area 8
Glendale Disposal Area
Galena Park, Texas

PLATE A39



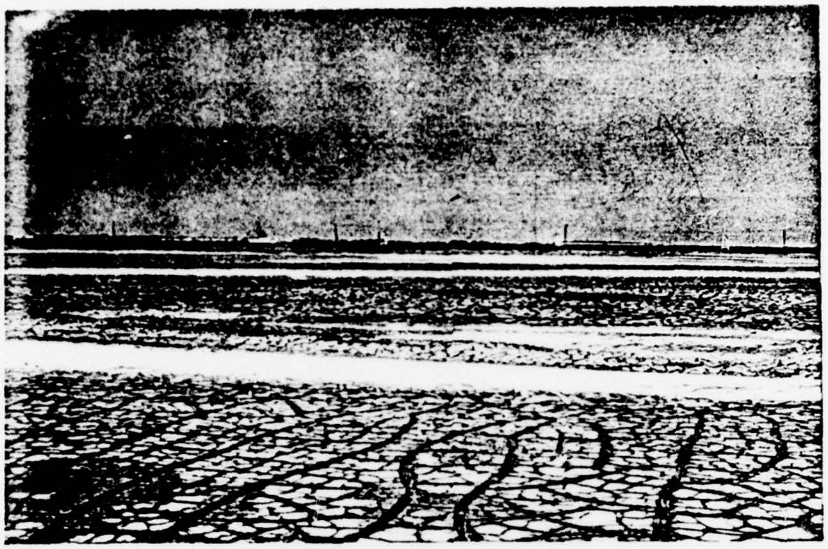
Galveston District
Area 9
Northeast of Galveston, Texas

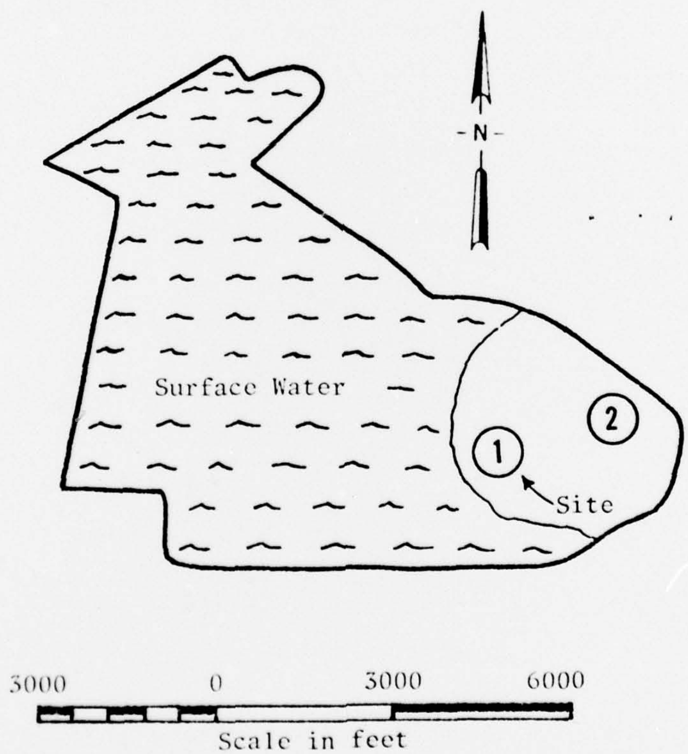
PLATE A40



Galveston District
Area 10
Northeast of Galveston, Texas

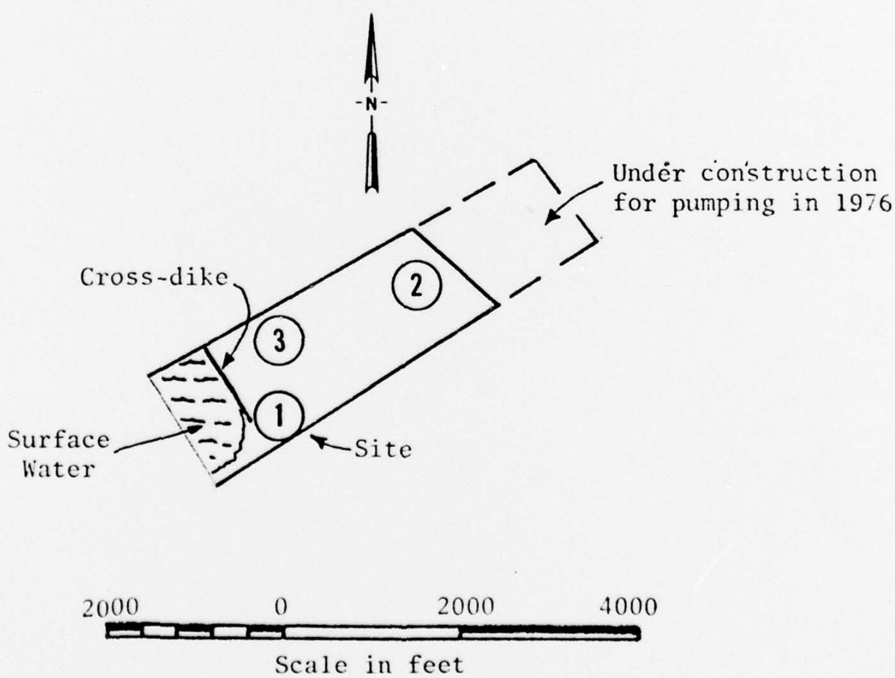
PLATE A41





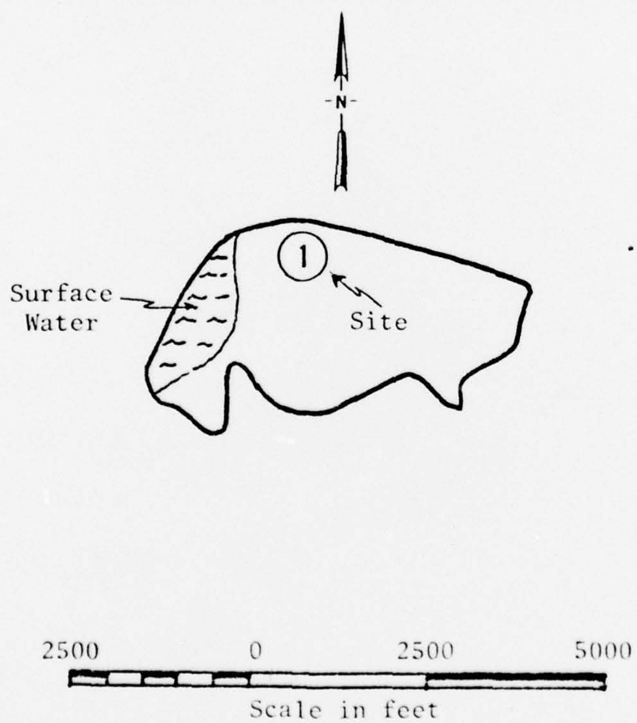
Galveston District
Area 11
Pelican Island, Texas

PLATE A42



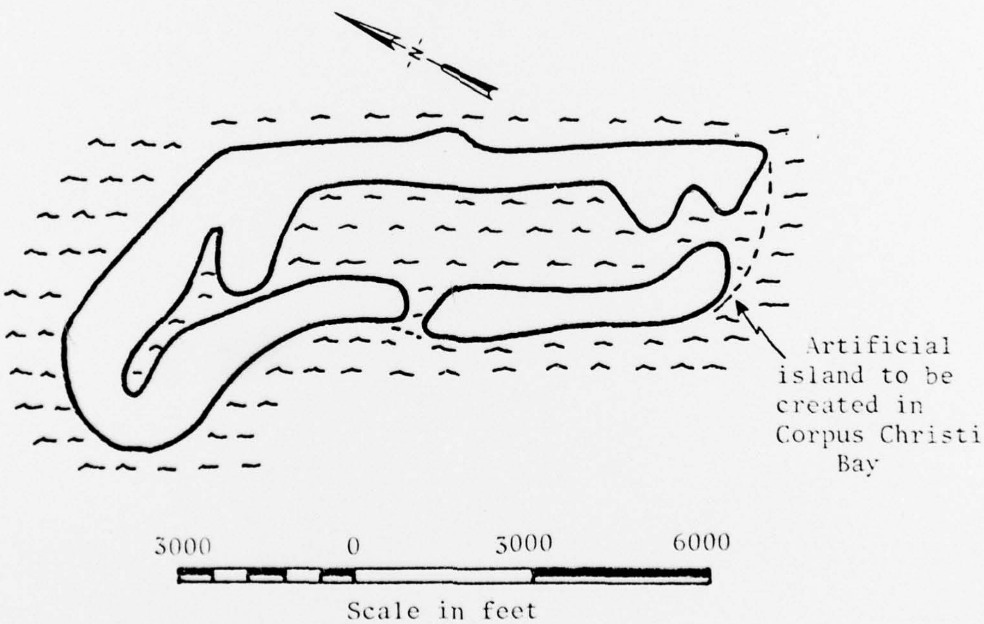
Galveston District
Area 12
Freeport, Texas

PLATE A43



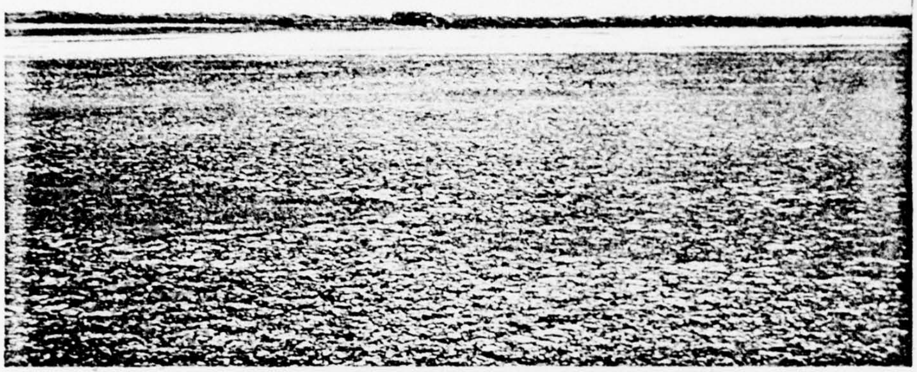
Galveston District
Area 13
Corpus Christi, Texas

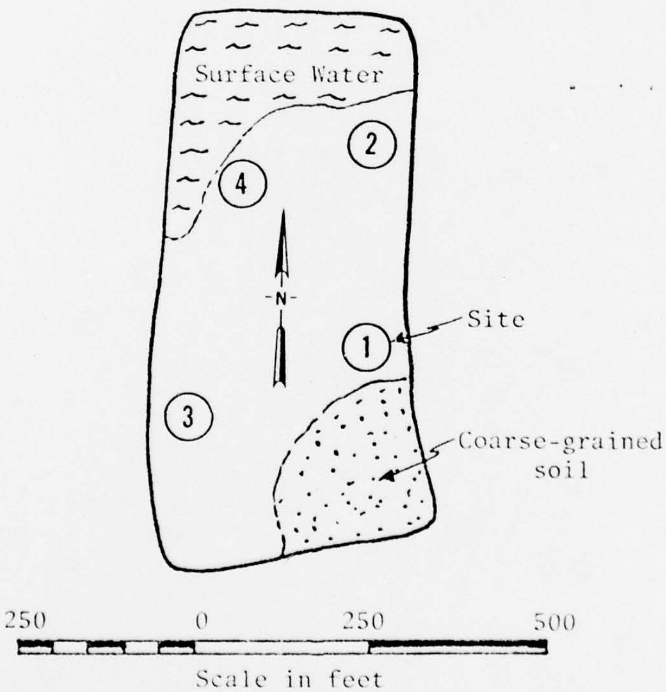
PLATE A44



Galveston District
Area 14
Corpus Christi, Texas

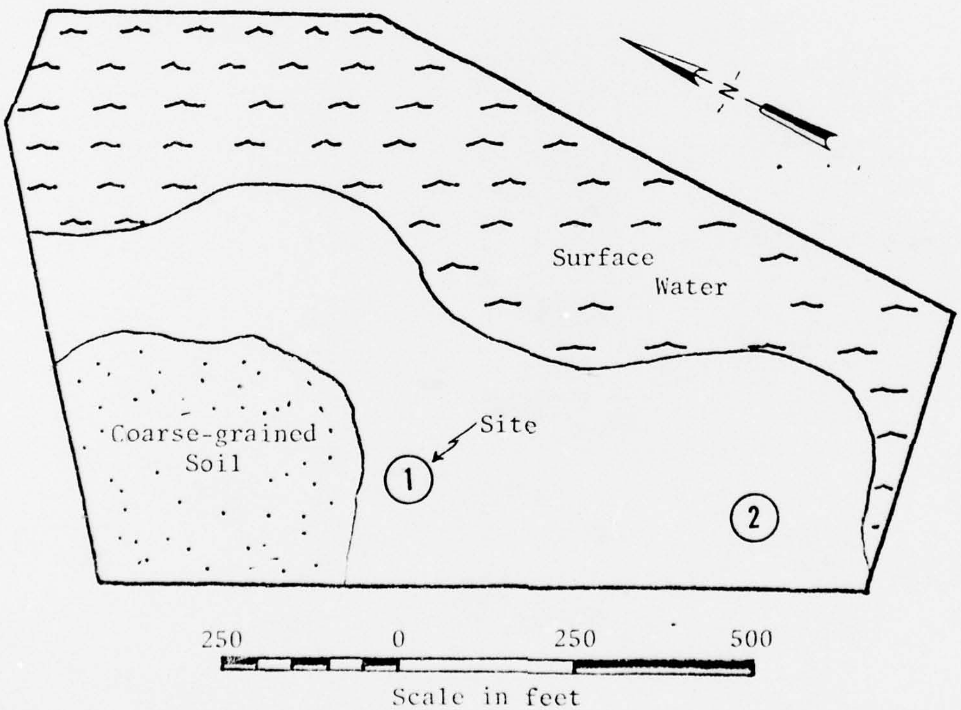
PLATE A45





Mobile District
Area 1
Blakeley Island, Alabama

PLATE A46



Mobile District
Area 2
Blakeley Island, Alabama

PLATE A47